2 DOCUMENTATION FOR TACQ.EXE

2.1 Program Capabilities

Program TACQ.EXE is capable of both unattended control of a time domain reflectometry (TDR) soil moisture measurement system and reduction of TDR waveforms to water contents. TACQ.EXE may be user configured to automatically or manually perform several tasks including:

1) Control Tektronix 1502B or 1502C TDR cable testers including setting distance to probe, Vp and DIST/DIV settings, vertical gain setting and vertical position of waveform, and filtering. Control a modified (see Chapter 7) Tektronix 1502 to output an analog wave form for external digitization. With the optional TR-302, turn off power to any Tektronix cable tester when not in use.
2) Individually control up to 16 Dynamax and 16 Campbell Scientific, Inc. coaxial multiplexers (using 6 pins of the computer's parallel port). More than 16 multiplexers of each type may be controlled if multiplexers using the same address are positioned on different branches of the connection tree.
3) Acquire waveforms from Tektronix 1502B, 1502C, or modified 1052 cable testers.
4) Acquire relative voltage data needed for calculation of bulk electrical conductivity (BEC) (1502B/C only).
5) Acquire temperature data from thermocouples using analog to digital conversion cards (Measurement Computing models CIO-DASx, PCI-DASx, and PC104-DASx, Middleboro, MA).
6) Reduce waveforms to travel times, apparent dielectric constants and water contents.
7) Control algorithms used for reduction of waveforms to water contents.
8) Recommend Vp and DIST/DIV settings for best wave form width on screen for any length probe.
9) Save to ASCII files either waveforms alone; travel times, apparent dielectric constants, and water contents alone; or both. Selectively save these data for chosen probes.
10) Selectively (for chosen probes) save data for BEC calculations to a separate ASCII file.
11) Read in ASCII waveform files previously collected; and, under user control or automatically, reduce the waveforms to travel times, apparent dielectric constants, and water contents.

2.2 Hardware and Operating System Requirements

The program will run on an IBM PC/XT or AT compatible computer with 640 kbytes of RAM and a floppy disk. However a hard disk or other mass storage is recommended for better performance, and if wave forms are to be saved to file. Computers with a PCMCIA card slot may use an SRAM card, flash RAM card, or hard disk card to store data. Most subnotebook computers are equipped with such a slot and may be configured to boot DOS and run TACQ.EXE from an SRAM PCMCIA card thus eliminating the need for a hard disk or floppy disk and decreasing power usage (see the File Formats section for limitations on data storage). The program will run on a Hewlett Packard model 200LX palm top computer if all other programs are terminated, and will correctly acquire data from a Tektronix model 1502B/C; but since the HP200LX does not have a parallel port it cannot be used to control multiplexers.

Although it is a DOS program, TACQ will run under Windows in a DOS box. This is not recommended for data acquisition because Windows puts a control layer between the DOS box and the parallel and serial port hardware. This control layer causes timing problems for communications with cable testers and multiplexers and prevents these peripherals from working reliably under Windows. For interpreting wave forms acquired elsewhere, the program may be run in a DOS box successfully if the box is kept in the foreground.

For data acquisition on a Windows 95 system, the following steps are recommended to run TACQ in a real DOS system with no Windows in the background.

1) Open My Computer and look for TACQ.EXE on your hard disk. Left click on TACQ.EXE and drag it to the desktop. When the query box opens, choose to create a Shortcut to TACQ on the desktop.
2) Left click on the TACQ shortcut and choose Properties.
3) In Properties, click on the Program tab.
4) Click on Advanced and turn on MSDOS mode. This will make Win 95 exit and boot in DOS before running TACQ.
5) Click on "Specify a new MS-DOS Configuration". This will allow you to input lines into the text boxes for CONFIG.SYS and AUTOEXEC.BAT that are below that button.
6) Click on Configuration and turn on Expanded Memory (EMS) and any other things desired in the DOS session (CDROM, Mouse, etc.). But, remember that everything that loaded here will decrease the amount of memory available for TACQ. So only choose what is needed. Expanded memory must be enabled for TACQ to run quickly (otherwise it will swap modules to disk and run more slowly).
7) Enter any other desired boot instructions in the CONFIG.SYS and AUTOEXEC.BAT text boxes. Be sure to enter SET PROMPT=PG on one line of the AUTOEXEC.BAT so there will be a useful DOS prompt. (If PAUSE is entered as the last line of the AUTOEXEC.BAT file, it provides the user an opportunity to press Cntrl-C and get to the DOS prompt before TACQ runs.)
8) Save the changes and then double click on the TACQ shortcut to run it.
9) A warning should appear saying that Win95 is about to shut down. Click on Yes and the computer will reboot into DOS and run TACQ. If there is a PAUSE statement as the last line of the AUTOEXEC.BAT then the computer will pause before running TACQ and a key will have to be pressed to continue. When the user quits TACQ, the computer will reboot into Win95.

When running TACQ in a remote system, we usually do not want the computer to reboot into Win95 after a power failure or glitch that shuts down the system momentarily. To avoid rebooting into Win95, a boot diskette should be in the diskette drive. The following steps create such a diskette.

1) Make sure there is a PAUSE statement as the last line in the AUTOEXEC.BAT in the Properties for the TACQ shortcut (see above).
2) In Win95, double click on the TACQ shortcut and let it boot to DOS.
3) Press Cntrl-C when the system pauses and says to press any key to continue. The DOS prompt will appear.
4) Put a diskette in the A: drive.
5) Go to the C: drive and type SYS A: and then press Enter. This will install DOS on the diskette. You should see a file named COMMAND.COM on A: when you do a directory of A:.
6) Copy the CONFIG.SYS and AUTOEXEC.BAT files from the C: drive to the A: drive.
7) Go to the A: drive and type EDIT AUTOEXEC.BAT and press Enter. This should put you in the DOS editor with the AUTOEXEC.BAT file in the editor.
8) Remove the PAUSE statement.
9) On the line that runs TACQ, put a space and the word AUTO after TACQ.EXE. This line will probably be the next to the last line in the AUTOEXEC.BAT file. It will begin with CALL and end with TACQ.EXE. The path to TACQ.EXE on your hard disk will be there as well.
10) Remove the last line of the AUTOEXEC.BAT file. It will probably read C:\WINDOWS\WIN.COM /W or something similar. This is the line that causes the computer to reboot to Win95 after TACQ runs. Save the AUTOEXEC.BAT file.
11) Reboot the computer with the diskette in the A: drive and DOS will boot and run TACQ.

If the computer is rebooted without the diskette in the A: drive it will first boot to DOS and run TACQ. After the user quits TACQ, the system will reboot to Win95. Do not change the AUTOEXEC.BAT and CONFIG.SYS files on the C: drive. Doing so may cause the computer to not be able to reboot to Win95.

The program will use CGA, EGA, VGA (in EGA mode), ATT, or Hercules graphics. To use Hercules graphics, the memory resident program MSHERC.COM should be run before TACQ.EXE. A parallel port is required for control of multiplexers. A serial port is required to acquire data from either the digital Tektronix 1502B or 1502C cable testers, or the modified Tektronix 1502 cable tester. The program can automatically scan serial ports COM1 through COM4; and will find the 1502B/C cable tester if it is connected and selected in Software Setup. The program will then set the cable tester to the maximum baud rate of 19,200 for the 1502B/C or 9,600 for the modified 1502. If there are multiple serial and parallel ports, the user may specify which to use. The program has been used on IBM compatible computers with CPUs ranging from 8088 to Pentium including laptop and notebook computers. Note that if the program is set for the Tektronix 1502B or 1502C and the serial cable is not connected, or the cable tester is not turned on, the program will stop and query the user after trying all possible serial ports (See Section 1.2). TACQ will run with no cable tester connected, but the user should indicate that there is no cable tester in Software Setup. Install the program by copying files TACQ.EXE, TACQ_TDR.INI, and TACQ.INI to the desired directory on the computer's hard disk. If you do not have TACQ_TDR.INI and TACQ.INI you can still run the program and create them in Software Setup.

2.3 Running TACQ Automatically

If automatic start-up of the program is desired (e.g. in case of a power failure you might want the program to re-start automatically when the power comes back on and the computer reboots) make the following lines the last 2 lines in the computer's AUTOEXEC.BAT file:

```
CD  \path
TACQ  AUTO
```

where "path" is the path to the subdirectory where TACQ.EXE and the *.INI files reside. If the program is installed on the root directory of the boot drive (usually C:) then only the following line is necessary:

```
TACQ  AUTO
```

Note that a space should separate the words 'TACQ' and 'AUTO'.

The program also may be run from a batch file so that control is returned to the batch file after all TDR probes are read. This is done by using the line:

```
TACQ  AUTOSTOP
```

This is useful when other programs will be using the data output by TACQ. For an example of this use of TACQ in an automatic irrigation system see Lascano, R.J., R.L. Baumhardt, S.K. Hicks, S.R. Evett, and J.L. Heilman. 1996. Daily measurement and calculation of crop water use. Pp. 225-230 *In* C.R. Camp, E.J. Sadler, and R.E. Yoder (eds.) Proceedings of the International Conference on Evapotranspiration and Irrigation Scheduling. Nov. 3-6, 1996, San Antonio, Texas, U.S.A. 1166 pp.

2.4 Main Menu

Run TACQ.EXE by typing TACQ and pressing the Enter key. The second and third lines of the main menu (Fig. 2-1) display the software version date, location suffix, propagation velocity (Vp), distance per division setting (DIST/DIV) and parallel port that will be used to control multiplexers (LPT1 or LPT2). The location suffix can be changed by the user during Software Setup (accessed by pressing 'S' at the main menu) and can be up to 3 characters. This suffix is used in all automatic data collection file names so that files from different installations can be differentiated. The Vp and DIST/DIV values shown are those selected in Software Setup. If a modified (Chapter 7) Tektronix 1502 cable tester is used, the user must make sure that the Vp and DIST/DIV settings in the program and those on the cable tester are identical. If the Tektronix 1502B or 1502C are used then the displayed Vp and DIST/DIV are not necessarily those used by the program since the user can select different Vp and DIST/DIV settings for each probe (see Section 2.6). See Chapter 7, Principles and Methods for Time Domain Reflectometry, for information on how Vp, DIST/DIV and probe lengths are used to compute travel times, apparent dielectric constant, and water content. The fourth line shows the hardware used for TDR data acquisition as selected by the user in setup. The fifth line shows the drive and path that the program will use for writing files. This may be changed in Software Setup. The line at the bottom of the screen gives the month, day of month and year; hour, minute and second; and the sequential day of year with January 1 as day 1. Note that directions given here and later in this document will not result in acquisition of TDR data if the cable tester, multiplexers and TDR probes are not correctly connected to the computer and to each other. See Section 1 for directions on system hookups. The main menu presents several choices for data acquisition, wave form interpretation, software setup, and control of hardware as will be discussed below.

```
TACQ, Time Domain Reflectometry (TDR) System Control Program.  USDA-ARS,
2300 Experiment Station Road, Bushland, TX 79012. Beta 09-02-1999, 09:38:16
Location Suffix: TAC       Vp: .54,  DIST/DIV: .5 m.  Using LPT1.
  Using Tektronix 1502B/1502C TDR cable tester (com1:19200,n,8,1)
Writing to: C:

Select from the following:
   Software Setup.
   File functions - Acquire & save to file, Read file
   Bring in a wave form.
   Graph TDR data.
   Control TR-200 or SDMX-50 coaxial multiplexer.
   Control Tektronix 1502B/C TDR cable tester.
   Quit.
Enter your selection:




                                        12-19-2000.   22:27:18.  DOY: 246
```

Figure 2-1. Main Menu of program TACQ.

2.4.1 Software Setup

Press S at the Main Menu to enter Software Setup (Fig. 2-2). The basic setup parameters are shown, and can be changed, here; including which cable tester is to be used, which serial port and at what speed, which parallel port and what pins on that port, the write path for files, automatic data acquisition file names, filtering level (1502B/C only), Vp and DIST/DIV, the time interval for automatic data acquisition, and the number of times to acquire data at each interval. Not visible on the screen, but able to be changed from it, are the multiplexer and probe connections, and the type of data to be automatically acquired for each probe. If a 1502B/C cable tester is being used then the distance to each probe, and individual Vp, DIST/DIV, filter, gain, and vertical offset values for each probe, may be set.

2.4.1.1 Press T to choose a TDR instrument. A prompt will appear at the bottom of the screen. The up and down cursor keys allow selection of one of three choices: No wave form acquisition, Tektronix 1502B/1502C TDR cable tester, or Serial Interface to modified Tektronix 1502 cable tester. In most cases the 1502B/C cable tester is used. If TACQ is being used in the laboratory to interpret wave forms from files collected elsewhere, and if no cable tester is connected to the computer, then choosing 'No wave form acquisition' will avoid some problems that might occur on start up if the program were to attempt to communicate over a serial link that didn't exist. Pressing A will expand the selection choices to include the Measurement Computing (formerly ComputerBoards) analog to digital (A/D) conversion cards (Middleboro, MA); and two other A/D cards that are not currently supported. If the CIO8 is chosen, the user will have to install and configure this card and connect it to the analog wave form output of the Tektronix 1502 TDR cable tester (usually using the Tektronix X-Y Output Module). The user will also have to modify the cable tester for computer controlled toggling of wave form output by installing a relay in parallel with the toggle switch in its front panel. Details of cable tester modifications will soon be found in Chapter 8 of this manual.

```
                                 SOFTWARE SETUP
TDR instrument:        Tektronix 1502B/1502C TDR cable tester
1502 defaults:         Vp: 0.99, DIST/DIV: .05 meters
                       Filter: No override.
Serial Port:           COM1:, 19200 baud, Send/Receive delay: 0, Wait: 3
Parallel Port:         LPT1:. Pins for TR-200: DATA 2, CLOCK 3, SDE 4
                              Pins for SDMX50: DATA 6, CLOCK 7, SDE 8
                              Delay between clock ticks is approx. .006 s.
                              Power Control Pin: 9. Continuous power.
Other Data Acquisition: None
File Names:            Wave forms: 2000354T.TAC. Water contents: 2000354W.TAC
Write to: C:           Bulk electrical conductivity: 2000354E.TAC
Acquisition Interval:  1800 s. Data is acquired 1 times at each interval.
Set Date/Time:         12-20-2000, 22:29:07
Multiplexer & Probe Connections:
Probe Cable Length, Vp, DIST/DIV:
Interpretation methods:
Press T, 1, S, P, F, W, A, D, O, M, L, I or Esc:
```

Figure 2-2. Software setup screen of program TACQ.

2.4.1.2 Press 1 to choose global defaults for propogation velocity factor, Vp, distance per division on the cable tester screen (and the computer screen), DIST/DIV, and filtering. If a modified 1502 cable tester is used then the Vp and DIST/DIV settings made here will be used for all probes; and these settings must match the cable tester front panel settings. The Vp and DIST/DIV settings change the apparent width of the wave form on the cable tester screen. They must be adjusted so that the entire wave form can be seen on the screen at one time. Since wave forms become wider as soil water content increases, it is necessary to choose settings that allow the entire wave form to be seen when the soil is practically saturated. For example, for 20 cm probes a Vp setting of 0.99 and DIST/DIV setting of 0.5 feet will work well. TACQ will provide recommended settings of Vp and DIST/DIV to provide optimum screen width for each probe length; corresponding to an expected maximum or saturated water content input by the user (0.45 is used if the user does not input a value). If the modified Tektronix 1502 cable tester is used then two choices of DIST/DIV will be shown that, with the current Vp setting, would result in screen widths that are closest to the optimum. The first choice will provide a screen width that is at, or smaller than, the optimum; and the second choice of DIST/DIV will provide a screen width that is at, or larger than, the optimum. The percent error from the optimum will also be shown. See Section 7.6.1 and Appendix 7-A for discussion of what the optimum screen width is and how the best DIST/DIV and Vp values are found. If a 1502B or 1502C cable tester is used then the Vp and DIST/DIV settings made here are overriden by the Vp and DIST/DIV choices made for each probe (See Section 2.6. Choices for individual probes may be made by pressing L at the Software Setup screen.)

The 'Filter' setting is only applicable if the 1502B/C cable testers are being used. If the default is 'No override' then the individual filter settings made for each probe (see Section 2.6) will take effect. Otherwise the filter setting (number of wave forms averaged into the one recorded wave form) chosen here will take precedence for all probes.

2.4.1.3 Press S to change serial port settings. Note that these settings cannot be changed if a cable tester is not chosen (see above). A series of prompts will appear at the bottom of the screen. Enter zero for the transmit/receive delay unless the cable is longer than 2 m, in which case increase this setting until serial communications are stable. A delay of 0.1 s has been shown to work for a serial cable (e.g. TR-2001) 1000 feet long (18 gauge, shielded, twisted pair). Accept the default value of 2 for the wait for cable tester response, unless the cable is longer than 2 m in which case you may have to increase the time to obtain stable serial communications. A value of 2 has been shown to work with the 1000 ft cable. Enter a baud rate of 19,200 for the 1502B/C cable testers, or 9600 for the modified 1502 cable tester with serial interface. These rates are for cables of 2 m length - they may have to be reduced for longer cables. A value of 9,600 was shown to work for the 1000 ft cable connected to a 1502B cable tester. Enter the number for the serial port being used (usually 1 or 2, see your computer's documentation).

2.4.1.4 Press P to change parallel port settings and TDR instrument power control. A series of prompts will appear at the bottom of the screen (Fig. 2.3). If the computer has more than one printer port, a choice of ports will be offered. Successive prompts will ask for pin numbers to be used for various tasks. Note that pressing Enter will cause the pin assignment displayed to be retained. Normally pins 2, 3, and 4 are used for the data, clock, and serial device enable (SDE) lines controlling the TR-200 multiplexer (see Chapter 5 and addendum 1). These are the defaults for the TR-2200 cable (see Chapter 3) and will usually be the defaults offered by the program. If the assignments have been changed they should be restored to the default values if the TR-2200 cable (Chapter 3) is to be used. The user may construct a cable using different pin assignments if necessary. Pins 6, 7, and 8 are used for the data, clock, and SDE lines controlling any SDMX50 multiplexers attached. Note that both multiplexers are controlled by synchronous serial signals sent through the parallel port. This is not the same as the asynchronous serial signal available at the computer's serial port(s). The delay between clock ticks on the control lines is normally about 0.006 s, but this should be increased if multiplexer control is compromised by long cable lengths.

For many users, power to the TDR instrument will be on at all times. However, Chapter 6 describes two power control devices that may be used to conserve power in battery operated systems (TR-302) or isolate the system from AC power line noise (TR-304). If these devices are not used then the defaults offered in the relevant prompts may be accepted (Fig. 2.3). Pin 9 is normally used to control power to the TDR instrument if the optional TR-302 power control module is installed (Chapter 6). If the TR-302 is not installed, enter 5 here so that the TR-2200 cable and pin 9 may be used to control the AC power control device described below. The default setting for the delay after power is turned on at the cable tester is zero. With this setting, power is always on at the TDR instrument, even with the TR-302 installed. If it is desired to turn off power to the TDR instrument after each automatic data acquisition cycle then enter a value of at least 5 s here. The delay is required to allow the TDR instrument to initialize its serial communications firmware and hardware before the computer attempts to begin communications over the serial port. If the TR-302 is not used, then enter 9 for the pin used to signal the optional model TR-304 remote controlled AC power strip on and off; otherwise enter 5. If both the TR-302 and the TR-304 are used, the TR-2200 cable must be modified to provide an extra wire to control one of the devices. At the last prompt, enter zero to keep AC power on always; or enter 1 or more seconds for the delay to have the AC power turned off during data acquisition. This sometimes eliminates AC noise in the TDR instrument. To use this option, the instrument must have an internal battery or be externally battery powered.

```
Only Parallel port # 1 exists.
It will be used for system control.
Press any key to continue...
--------------------------------------------------------------------------
Parallel port pins used to communicate with Vadose coaxial multiplexer
are normally: DATA 2, CLOCK 3, SDE 4.
Enter pin number for DATA. Press <Enter> for default = 2
Acceptable parallel port pin numbers are: 2, 3, 4, 5, 6, 7, 8, 9:_
--------------------------------------------------------------------------
Enter pin number for CLOCK. Press <Enter> for default = 3
Acceptable parallel port pin numbers are: 3, 4, 5, 6, 7, 8, 9:_
--------------------------------------------------------------------------
Enter pin number for SDE. Press <Enter> for default = 4
Acceptable parallel port pin numbers are: 4, 5, 6, 7, 8, 9:_
--------------------------------------------------------------------------
Parallel port pins used to communicate with SDMX50 coaxial multiplexer
are normally: DATA 6, CLOCK 7, SDE 8.
Enter pin number for DATA. Press <Enter> for default = 6
Acceptable parallel port pin numbers are: 5, 6, 7, 8, 9:_
--------------------------------------------------------------------------
Enter pin number for CLOCK. Press <Enter> for default = 7
Acceptable parallel port pin numbers are: 5, 7, 8, 9:_
--------------------------------------------------------------------------
Enter pin number for SDE. Press <Enter> for default = 8
Acceptable parallel port pin numbers are: 5, 8, 9:_
--------------------------------------------------------------------------
Parallel port pin used to signal power on (pin high) or off (pin low) for
Tektronix 1502 is normally: 9
Enter pin number for power control. Press <Enter> for default = 9
Acceptable parallel port pin numbers are: 5, 9:_
--------------------------------------------------------------------------
Enter integer to set delay between clock ticks for parallel port control.
Delay time is approx. the integer value times 0.003 s.
Current delay time is approx. .006 s.
Press <Enter> for default = 2_
--------------------------------------------------------------------------
Currently a 0 s delay occurs after power is turned on at the 1502.
Power is on permanently.
Enter number of s to delay (Enter 0 for permanent power on):_
--------------------------------------------------------------------------
Parallel port pin used to signal AC power strip off (pin high) or on (pin low)
is normally: 5
Enter pin number for AC power control. Press <Enter> for default = 5
Acceptable parallel port pin numbers are: 5:_
--------------------------------------------------------------------------
Currently a 0 s delay occurs after the AC power strip is turned off.
Power is on permanently.
Enter number of s to delay (Enter 0 for permanent power on):_
```

Figure 2-3. Prompts for parallel port settings in the order that they appear and separated by horizontal lines.

2.4.1.5 Press O to set up other data acquisition. If the computer is equipped with a CIO-DASx, PCI-DASx, or PC104-DASx series analog to digital conversion board and a CIO-EXP series multiplexer board (Measurement Computing, formerly ComputerBoards, Inc., Middleboro, MA), that equipment may be used to acquire temperatures using thermocouples. Other than TDR, that is the only data acquisition supported at this time. The CIO-DAS8 series A/D boards are ISA bus cards that may be used with IBM PC/AT compatible computers. The PCI-DASx are equivalent boards for the PCI computer bus; and the PC104-DASx boards are for embedded computers built to the PC104 bus specification. Successive prompts will query the user for the card's base address (often 768), the output channel for MUX-32 (EXP-32) channels 0-15 (may be 0), the output channel for MUX-32 channels 16-31 (may be 1), the gain for MUX-32 channels 0-15 (may be 1), the gain for MUX-32 channels 16-31 (may be 800 for thermocouples on those channels), the output channel for the cold junction temperature (may be 7), and the channel for TDR data. The latter may be 0 if the DAS8 is used to digitize TDR wave forms from a Tektronix 1502 cable tester. The scenario supported by the setup values given above is for thermocouples connected to MUX-32 channels 16-31. There is also provision for digitizing wave forms on channel 0, but this will not occur unless enabled when choosing a TDR instrument (Section 2.4.1.1). The user is encouraged to read the documentation that comes with the DASx and EXP boards for details of their use.

2.4.1.6 Press F to set files for automatic data acquisition. The file names prefixes are assigned automatically (the prefix is the part of the file name, up to 8 characters in length, to the left of the period). The user can change the suffix (up to 3 characters after the period). This allows files from different installations to have different names. The file name convention is yyyydddX.SUF where yyyy is the year (1997 for 1997, or 2000 for 2000); ddd is the serial day of the year starting with 1on January 1 (often known as the Julian day); X is a letter identifying the file data type as explained below; and SUF is the user supplied suffix. The X identifier is T for files containing wave form data; W for files containing travel times, water contents and apparent permittivities; E for files containing relative wave form voltage data for bulk electrical conductivity calculations, and C for files containing thermocouple data. The user may chose to save data as water contents only (W files) only, as wave forms (T files) only, or in both files. The safest approach is to save data in both forms. Then, if there is any question about how the wave forms have been interpreted or about noise in the system, the wave forms can be re-interpreted by TACQ under user control (see Section 2.4.3) to find out just when and where in the system a problem occurred. However, there are large savings in disk space if only water contents are saved to file (see Section 2.8). Note that the user also controls what kind of data are saved to files in the multiplexer and probe connection setup (see Section 2.5). For each probe the user may chose to save only wave form/water content data, or only BEC data, or both. For instance, if for all probes the user has chosen to save only wave form/water content data then no data will be saved to E files. The final prompt presented to the user will be a choice of appending to, or overwriting the current files. Pressing A or the Enter key will cause the existing files to be saved and these will be appended to during the next automatic acquisition cycle.

2.4.1.7 Press W to set the write path. The disk drive and subdirectory path (if any) may be specified here. Pressing W brings up a directory of the current drive and path (usually the drive and path from which TACQ was run). The user may change drives and go up and down through the subdirectories on each drive to find the drive and path (if any) desired for file storage. Scenarios where this may be useful include running TACQ from a solid state disk in an embedded computer and writing data to a PCMCIA hard disk or ATA flash memory disk; or reading wave form data from a CDROM disk where it has been archived, interpreting the wave forms, and writing the water contents to a writeable drive elsewhere in the system. Note that changing the write path will cause the Software Setup (TACQ.INI) file to be written to the new write path. After saving the Software Setup and exiting TACQ, the user should make sure to copy the TACQ.INI file to the drive and subdirectory from which TACQ will be run in the future.

2.4.1.8 Press A to set the automatic data acquisition interval. The interval is in seconds. A complete automatic acquisition cycle will be started at each time that is an integer multiple of the acquisition interval, beginning with midnight. A complete cycle means that the software will switch the multiplexers to connect each probe to the cable tester and acquire and save to file the kinds of data that the user has enabled for each probe. Of course, a probe must be configured in software (see Section 2.5, Multiplexer & Probe Connections, below) to reflect the physical connections of multiplexers and probes before data acquisition can occur. Also, any thermocouple data (see Section 2.4.1.5) will be acquired and written to file immediately after the TDR data are acquired. After setting the interval, the user will be prompted to set the number of times to acquire data at each interval. This number is normally one. But, some users may desire to obtain multiple readings from each probe at each acquisition interval in order to calculate statistics on the data.

2.4.1.9 Press D to set date and time. This changes the software clock but not the hardware clock. If the computer reboots, the hardware clock will be used to set the new software clock. This is an important distinction for unattended automatic acquisition. If the computer reboots after a power failure or due to a voltage transient, the program may be restarted automatically (see instructions above for setting this up in the AUTOEXEC.BAT file). But if the hardware clock is wrong, the file names and dates and times in the files will be wrong because the hardware clock is used to reset the software clock when the computer reboots. See your computer's documentation for setting the hardware clock. This is usually done in CMOS setup which, for many computers, can be entered by pressing the Esc or Del keys during computer startup. Some computers use the Ctrl-Alt-S key combination, entered at the DOS prompt, to enter CMOS setup. See your computer's documentation if CMOS setup cannot be entered in one of these ways. We suggest setting the hardware clock during every visit to remote, unattended sites.

2.4.1.10 Press M to set Multiplexer and Probe Connections. All the physical connections between multiplexers and probes must be set up in software in order for the system to acquire data automatically and unattended. Also, this must be done before the cable lengths to probes, and the individual probe Vp and DIST/DIV settings are specified (see the next subsection). During this part of software setup the length of each probe is recorded, and the user makes choices about what kind of data are to be saved for each probe. Choices include water contents, relative wave form voltages for bulk electrical conductivity calculations, or both. After setting up a probe to be attached to a particular channel of a particular multiplexer, the user may set the cable length, Vp, and DIST/DIV values for that probe interactively if a Tektronix 1502B/C cable tester, optional multiplexer and probe(s) are already installed. See Section 2.5, Set Multiplexer and Probe Connections, for detailed instructions on doing this.

2.4.1.11 Press L to set cable lengths to probes, and individual probe Vp and DIST/DIV settings. A complete explanation of this process is given in Section 2.6, Setting Cable Lengths, Vp, and DIST/DIV. An abbreviated description is included here for continuity. If a Tektronix 1502B or 1502C cable tester is being used, pressing L at the Software Setup menu allows the user to set in software the distance to each probe individually; and to set the Vp and DIST/DIV settings for each probe to the optimal settings for data acquisition given that probe's length. These settings must be made in order for the system to correctly find the wave form for each probe. In order for this part of software setup to proceed correctly, the physical connections that the user has indicated in software (see Section 2.4.1.10) must in fact exist and the multiplexers must be properly connected to power and switching signals using cables TR-2200 and TR-250; and to each other and the cable tester using cables TR-1058. Also the multiplexer and probe connections settings described in the previous section must be made before the settings described here can be successfully completed. After L is pressed, the screen will clear and briefly display a message indicating to which probe on which multiplexer the system is switching. The system automatically switches to the first probe on the first multiplexer (multiplexer 2) that is connected to multiplexer 1. If there is only one multiplexer the system will switch to the first probe on it. Make the distance, Vp, and Dist/Div setting changes needed to properly position that probe's wave form on the screen (see Section 2.6). When finished adjusting the wave form, press N to see the wave form for the next probe on multiplexer 2; or, press G to see the graph of the present wave form with the tangent lines fitted for water content determination. Right now it is preferrable to press N rather than G. After all the wave form positions are set up you can go back and look at the fitting. After the user presses N, the system switches to the next probe on multiplexer 2. This continues until all connected probes (as chosen by the user in software Connection Setup) are set up. The software then switches to the next multiplexer (multiplexer 3) connected to multiplexer 1 and allows set up for the first probe on that multiplexer, then the second probe, etc. This process continues until all probes that were indicated as connected in Connection Setup have been set up for distance, Vp, and Dist/Div.

2.4.1.12 Press I to change graphical interpretation methods. The algorithms that control the reduction of wave forms to water contents may be changed via a set of submenus accessed by pressing I. The user also has access to these changes when the wave form is displayed after B is pressed, or when the wave form is displayed as the user is reading in a file containing wave forms and reducing them to water content. Simply press D for re-do when the graphical interpretation screen is displayed. It is more useful to change these settings while a wave form is displayed. Access to these submenus is also given after the distance to a probe, Vp and DIST/DIV are set in the setup part of the program. See Section 2.6, Setting Cable Lengths, Vp, DIST/DIV. Another way to access the algorithm change submenus is to press F at the main menu and then press A for automatic data acquisition and then immediately press T for test. The computer will switch the multiplexer(s) to display each probe that has been specified (by the user in setup), acquire each wave form and display it. Data are not necessarily saved to file in test mode. A final way to access the algorithm change submenus is to press F, and then S for single wave form acquisition at the Main Menu. After the wave form is properly positioned, press G and the graphical interpretation screen will appear. See Section 2.7, Algorithms for Reducing Wave Forms to Water Contents, for information about changing these settings. Settings are saved in file TACQ_TDR.INI.

2.4.2 Bring in a Wave Form

Pressing 'B' at the Main Menu will cause the system to acquire a single wave form, display the wave form and first derivative, and reduce the wave form to a water content. If a modified Tektronix 1502 is used, the wave form should first be found by adjusting the horizontal and vertical position knobs. The wave form should be adjusted using the Vp, DIST/DIV, and horizontal position (distance) knobs so that the first peak is at, or just to the right of, the first vertical division mark on the cable tester screen; and, the second inflection occurs somewhere in the right hand half of the screen. See Sections 1.2.2 and 2.6 for information related to finding the wave form and correctly positioning it. See Section 7 for details of wave form shapes. If the Tektronix 1502B/C cable testers are used, the wave form may be placed on the screen manually or by program control. To adjust the wave form manually, first unlock the cable tester front panel by pressing 'C' at the main menu to control the cable tester and then 'U' to unlock it. Horizontal position, Vp, and DIST/DIV may then be set on the cable tester front panel. Several software controls are possible in the submenu that controls the 1502B/C. These may be accessed by first pressing 'C' to "c-ontrol TDR". These will not be discussed here because TACQ provides a wave form manipulation screen to adjust the wave form under program control after B is pressed at the Main Menu. Note that bringing in a wave form by pressing B does nothing to switch multiplexers to connect a specific probe to the cable tester. To switch to a specific probe and acquire data the user should press F at the Main Menu and then press S as discussed in the next section.

After pressing B, enter the probe length or press Enter to accept the default length. Data may be saved to files by entering a file name prefix of up to 8 characters; or the user may press Enter to avoid saving to a file. If the file name is already in use, the data will be appended to the file. Comments may be entered, or not, at the next prompt. A comment serves as an identifier to distinguish one data set from another. If a model 1502C or 1502B cable tester is used then the wave form manipulation screen appears next. Use of this window to position the wave form is discussed in Section 1.2.2. When finished positioning the wave form, the user may press N to continue or G to graphically interpret the wave form for travel times. If N is pressed then no data will be saved; so press G to continue and save data to files. The graphical interpretation window, and use of different methods for wave form interpretation are discussed in Section 2.7 and Section 7. For now it is assumed that the wave form is interpreted correctly, and that the user presses Y to accept the wave form. Several messages will appear on the screen relating to acquisition of wave forms (these are for BEC data) and then a prompt appears asking if the user wants to "Acquire another wave form". As many wave forms as desired may be acquired in this fashion. Data from subsequent wave forms will be appended to the files.

2.4.3 File Functions

Pressing 'F' at the Main Menu brings up options related to file management including automatically or manually saving wave forms to files, and reading wave form files previously saved and reducing those wave forms to travel times, apparent permittivities, and water contents (Fig. 2-).

2.4.3.1 Press A for automatic data acquisition mode. The program will wait until the next acquisition interval (set in Software Setup, see Section 2.4.1.6) and then acquire data from all probes in the system (or from a single probe if there is only one). The format of the files is discussed in Section 2.8, File Formats. Data are saved in files named according to the conventions shown in Software Setup. For each probe, the kind of data saved will depend on the choices made for that probe during Probe Connection Setup. The cable tester and probe(s) and any multiplexers must be correctly connected and the user must have set up the system by pressing 'S' at the main menu and specifying the connections in software as well as setting the distances to probes in software. As discussed above, a wave form must be displayed on the cable tester screen if the Tektronix 1502 is used. If a 1502B/C cable tester is used, then the multiplexers, and channels of these occupied by probes, the distances to probe, DIST/DIV, Vp, units and other settings; saved in the Setup part of the program; will be used to position the wave forms automatically on the screen. The program will wait until the next acquisition interval (set in seconds by the user in software Setup) and then acquire data for all probes as specified in software setup (particular probes may be excluded by the user from having data saved for them). Data are saved in files that have the file name suffix supplied by the user during Software Setup. File name prefixes are combinations of the year (e.g. 1997), the day of the year (sequential starting with day 1 on Jan. 1), and one letter codes that identify the type of data. These are T for wave form data, W for water content data, and E for data useful for calculating bulk electrical conductivity. For example, for day 321 of 1997 the wave form data file would be 1997321T.TAC if the suffix supplied by the user was TAC. See Section 2.8 for File Formats.

```
Acquire data Automatically (all multiplexers & probes),
Test &/or acquire data once from all multiplexers & probes,
Acquire Single wave form from specific probe & multiplexer,
Read wave form file & reduce to water content?:
```

Figure 2-4.

2.4.3.2 Press S to acquire Single wave forms. Data for user-specified probes are acquired, one probe at a time. These data are saved in ASCII files with a user supplied name prefix (up to 8 characters not including the period). The file formats are the same as for automatic acquisition; and, as for automatic acquisition, what data are saved is determined by the user in Software Setup. However, the file naming convention is different so that automatically and manually acquired data are not mixed. These files are named *.WAT, *.WAV, and *.BEC, where * is the user supplied name prefix. The WAT files contain the user supplied comment, travel times, water contents, and permittivities. The WAV files contain wave form data including Vp, DIST/DIV, and probe length. The BEC files contain data for calculation of bulk electrical conductivity. In addition there is a file named *.DIG that contains the same wave form(s) as in the *.WAV file; but in the format used by the Tektronix program SP.EXE. This file contains the user supplied comment, if any, and some additional information such as filter level, vertical offset, gain level, cursor position within the cable tester window, etc. that are not available in the other files.

After S is pressed the user is prompted for a file name. Pressing Enter alone results in no files being opened and no data being saved. But the user may still see the wave form on the screen, manipulate it, see how it is interpreted graphically for water content, and change the interpretation algorithms. If the user supplied a file name then a prompt for a comment will appear. Pressing Enter results in no comment being saved. Note that, since files are appended to - not overwritten, the user may enter the same file name repeatedly and not lose data. Next, the user specifies a multiplexer number, and an input channel on that multiplexer. If one or more multiplexers are used then these must be set up in the software Setup part of the program, and the multiplexers and probes physically connected and properly wired, before the user can switch to a particular probe.

If there is no multiplexer (the probe is connected directly to the cable tester) the user may press Enter alone when queried for multiplexer and again when queried for channel (probe) number. Pressing Enter alone twice in this manner results in default numbers of 1 for multiplexer and 1 for channel to be assigned. The user should be aware that the data save settings and other settings, made for channel 1 of multiplexer 1 in software Setup, will be used even though there is no multiplexer in the system.

Next, the probe length may be changed; or that specified in the Setup part of the program may be accepted by pressing Enter alone. After multiplexer, probe and probe length are specified, the program will switch multiplexers (or not, if there are no multiplexers) to provide a connection to that probe. A screen will be displayed showing the wave form and allowing the user to change Vp, DIST/DIV, units, etc.; and move back and forth along the wave form (see Figs. 2-6 through 2-9 for examples). This is the same wave form manipulation screen that is used to position the wave form in the Setup part of the program (see Section 2.6). This may be useful for examining the wave guide path between the cable tester and the probe for any shorts, impedance changes, etc. If the user has previously set up the probe connections and cable lengths and wave form positions as described in Sections 2.5 and 2.6 then the probe wave forms should already be positioned correctly. If not, then follow the directions in Section 2.6 for finding and properly positioning the probe wave form. If Q or N are pressed at this screen no data will be saved, and the user will be prompted whether or not to acquire another wave form. If G is pressed then the user will next see the graphical interpretation screen (see Figs. 2-10 and 2-14 for examples). Algorithms for wave form interpretation may be altered at this screen before continuing (see Sections 2.7 and 7 for guidance). Press Y to accept the interpretation or R to reject it. All data will be written to the files regardless of whether Y or R was pressed; but if R is pressed the travel time, water content, and permittivity fields will have zeros in them. As the BEC data are gathered, several transient messages may appear on the screen regarding reading of wave forms. When the data have been written to file the user is prompted whether or not to acquire another wave form. Pressing Y or the Enter key brings up the prompt for a comment on the next wave form. Pressing N causes the files to be closed and the Main Menu will appear.

2.4.3.3 Press T to enter a test mode that will cycle through all the probes and multiplexers as in automatic mode. Unlike automatic acquisition, the user will see the wave form manipulation screen for each probe and can also see the graphical interpretation screen by pressing G at the wave form manipulation screen. If a file name is entered all data will be saved to files. The file name suffixes are the same as those used for single wave form acquisition (*.WAT, *.WAV, *.BEC). This avoids writing to the automatic data acquisition files. In this way a snapshot of the entire TDR system may be taken at any time.

2.4.3.4 Press R to read in wave forms previously acquired and interpret them for travel times and water contents. Data that are in files acquired automatically are in the Multiplexed format (even if there was no multiplexer but only one probe connected directly to the cable tester). Press M to read these files. Data in the *.DIG files discussed in Section 2.4.3.2 may be read by pressing D for digital TDR. This is compatible with data saved by the Tektronix program SP.EXE. After pressing M or D the user will see a directory of file names. Using the page up and page down keys and the cursor up and cursor down keys the user may move the highlighted bar to highlight the desired file(s) and press the + sign to select them. Then, press I. If the user has selected more than one file, a file sort screen will be displayed so the user can sort the files into the order in which they should be processed (so data in TDR.DAT will be sequential). After pressing I or after the file sort is complete, the user will see the graphical interpretation screen with the first wave form in the file displayed. By pressing D for reDo the algorithms for interpretation may be modified, wave form smoothing level may be changed, and display characteristics (monochrome or color) may be chosen. Pressing Y will accept the interpretation and save the result to file TDR.DAT. Pressing R will save zeros to file TDR.DAT. Pressing A will cause the wave forms to be interpreted automatically without user intervention. See section 2.7 for more information on changing wave form interpretation methods.

2.4.4 Graph TDR Data.

The last wave form captured may be re-displayed by pressing 'G' at the Main Menu. If the wave form has previously been viewed in the graphical interpretation screen, its first derivative will have been computed and displayed, and it will be displayed here as well. If not, the first derivative will appear as a horizontal line through zero. The data and the first derivative of the data may be written to a file named WAVEFORM.PRN. The wave form data will be in the first column and the first derivative data will be in the second column. This is sometimes useful if the user wants to import the data into another program for computations or graphing.

2.4.5 Control Multiplexers

Any multiplexers connected to the computer may be manually switched to a given input channel by pressing '2' (for TR-200 multiplexers) or 'X' (for Campbell Scientific, Inc. SDMX50 multiplexers) and following the prompts. The user must know what address(es) the multiplexer(s) are set for. See Section 5, or the Campbell Scientific, Inc. documentation.

2.4.6 Toggle Modified 1502 Cable Tester

This Main Menu item is only seen if the user has selected the 1502 cable tester in software setup. If a modified Tektronix 1502 TDR cable tester is connected, the connection may be checked by pressing 'T'. This should cause a slowly moving dot to traverse the cable tester screen from left to right while the corresponding voltage is output on the Y output of the X-Y output module. This process takes 20 s.

2.5 Set Multiplexer and Probe Connections

Pressing M at the Software Setup screen begins the setup process for probe and multiplexer connections. A screen will appear showing all the multiplexers and the order in which they are connected:

```
Multiplexer number, type [in brackets], and address.
No.[TYPE] Address
1[1] 1

Enter number corresponding to location in tree (Press <Enter> to exit):
```

Typically for a new installation there will be only one multiplexer shown; and the onscreen code will be 1[1]1 which indicates multiplexer 1, type 1 (TR-200), and address 1. Press 1 and then Enter to set up this multiplexer. A multiplexer type choice will be shown:

```
Choose 1 Vadose multiplexer, 2 CSI SDMX50 multiplexer
Enter number:
```

Press 1 if it is a TR-200 or 2 if it is an SDMX50. Next, key in the multiplexer address and press Enter. The next screen shows the channels of the multiplexer (16 for the TR-200 and 8 for the SDMX50) and the status of connections to that multiplexer.

```
Channels connected to TDR probes are marked with pluses (+), channels
connected to other multiplexers are marked with number of multiplexer.
Working on multiplexer number 1, model: TR-200. Navigate with cursor keys.
  Type of   Channel    Probe     Acquire
Connection    No.    Length (m)   What?
               1       0.2000      ?
               2       0.2000      ?
               3       0.2000      ?
               4       0.2000      ?
               5       0.2000      ?
               6       0.2000      ?
               7       0.2000      ?
               8       0.2000      ?
               9       0.2000      ?
              10       0.2000      ?
              11       0.2000      ?
              12       0.2000      ?
              13       0.2000      ?
              14       0.2000      ?
              15       0.2000      ?
              16       0.2000      ?

Toggle Probe connection on/off, Make/Break Multiplexer connection,
Set cable length, Vp, DIST/DIV, etc., or <Esc>.
```

Note that there are no + signs below 'Connection' in the example above. This indicates that no probes have been assigned to any of the channels. Also, no numbers appear below 'Connection' indicating that no multiplexer connections have been assigned. Under 'Probe Length' the number 0.2000 appears for all 16 channels. Under 'Acquire What?' there is a question mark for each channel indicating that the desired type of data acquisition has not been set. The position of the highlighted area indicates which property (Connection, Probe Length, or Acquire What?) can be set and for which channel. The default position of the highlighted area is under 'Connection' for channel 1. Use the cursor keys to move the highlighted area across and up and down the screen. Note that the prompt at the bottom of the screen changes to reflect the kind of input that is needed from the user. Under 'Connection' the user can indicate a probe connection or disconnection, respectively, by pressing P to make a plus sign appear or disappear for each channel. Also the user can press M to make or break a multiplexer connection. If a probe has been connected by pressing P, the user may set the cable length, Vp, and DIST/DIV values for that probe by pressing S (assuming that the cable tester, multiplexer(s) if any, and probes are connected and working. See Section 2.6 for details of these settings). Under 'Probe Length' the user should change the assigned probe length to reflect the actual length of the probe connected to each channel. Under 'Acquire What?' the user should press W to acquire only water contents (and wave forms), press E to acquire only data (relative wave form levels) for calculation of bulk electrical conductivity, or press B to acquire both kinds of data. Also, the user can press N to acquire no data for a particular probe. When all probe connections, probe lengths and data collection choices are set as desired, press the Esc key. The next screen will be the Connection Setup screen (see beginning of this paragraph). Press enter to exit multiplexer connection setup and return to the Software Setup main screen.

If more than one multiplexer is needed then refer to the connection scheme in Fig. 1-2. Second level multiplexers should all be connected to the primary (first level) multiplexer. The following example explains how to connect two multiplexers to the primary multiplexer. Up to 16 multiplexers may be connected to the primary multiplexer. None of the second level multiplexers should share an address with the primary multiplexer; and only the 16th second level multiplexer should share an address with any other second level multiplexer. Press M for multiplexer and probe connections. The first multiplexer setup screen is shown

```
Connection Setup
Multiplexer number, type [in brackets], and address.
No.[TYPE] Address
1[1] 1

Enter number corresponding to location in tree (Press <Enter> to exit):
```

Press 1 and Enter and a multiplexer type choice will be presented:

```
Choose 1 Vadose multiplexer, 2 CSI SDMX50 multiplexer
Enter number:
```

Press 1 to select the Vadose multiplexer and a multiplexer address choice will be presented. Enter the address of multiplexer number 1, i.e. the address of the single multiplexer at MUX level 1. The next screen allows setting of connections for each channel on multiplexer 1. Position the highlighted area under 'Connection' and on the channel to which multiplexer 2 is connected (this is the first multiplexer in MUX level 2 that is connected to multiplexer 1). Press M and then C to set up the connection in software. Press 1 to indicate a Vadose multiplexer is connected and then enter the address of the multiplexer.

```
Channels connected to TDR probes are marked with pluses (+), channels
connected to other multiplexers are marked with number of multiplexer.
Working on multiplexer number 1, model: TR-200. Navigate with cursor keys.
  Type of   Channel    Probe     Acquire
Connection    No.    Length (m)   What?
                1       0.2000      ?
                2       0.2000      ?
                3       0.2000      ?
                4       0.2000      ?
                5       0.2000      ?
                6       0.2000      ?
                7       0.2000      ?
                8       0.2000      ?
                9       0.2000      ?
               10       0.2000      ?
               11       0.2000      ?
               12       0.2000      ?
               13       0.2000      ?
               14       0.2000      ?
               15       0.2000      ?
               16       0.2000      ?

Toggle Probe connection on/off, Make/Break Multiplexer connection,
Set cable length, Vp, DIST/DIV, etc., or <Esc>.
```

The next screen indicates that a multiplexer is connected to multiplexer 1 (in this case on channel 1). The word Multiplexer appears under 'Acquire What?'. The number 2 under 'Connection' shows that the connected

```
Channels connected to TDR probes are marked with pluses (+), channels
connected to other multiplexers are marked with number of multiplexer.
Working on multiplexer number 1, model: TR-200. Navigate with cursor keys.
  Type of   Channel    Probe     Acquire
Connection    No.    Length (m)   What?
     2          1       0.2000   Multiplexer
                2       0.2000      ?
                3       0.2000      ?
                4       0.2000      ?
                5       0.2000      ?
                6       0.2000      ?
                7       0.2000      ?
                8       0.2000      ?
                9       0.2000      ?
               10       0.2000      ?
               11       0.2000      ?
               12       0.2000      ?
               13       0.2000      ?
               14       0.2000      ?
               15       0.2000      ?
               16       0.2000      ?

Toggle Probe connection on/off, Make/Break Multiplexer connection,
Set cable length, Vp, DIST/DIV, etc., or <Esc>.
```

multiplexer is the second multiplexer. Note that 2 is not necessarily the address number for multiplexer 2.

Now move the highlighted area to channel 2 (assuming that this is where the third multiplexer is connected) and connect another multiplexer resulting in a screen like:

```
Channels connected to TDR probes are marked with pluses (+), channels
connected to other multiplexers are marked with number of multiplexer.
Working on multiplexer number 1, model: TR-200. Navigate with cursor keys.
  Type of   Channel    Probe     Acquire
Connection    No.    Length (m)   What?
    2          1       0.2000   Multiplexer
    3          2       0.2000   Multiplexer
               3       0.2000       ?
               4       0.2000       ?
               5       0.2000       ?
               6       0.2000       ?
               7       0.2000       ?
               8       0.2000       ?
               9       0.2000       ?
              10       0.2000       ?
              11       0.2000       ?
              12       0.2000       ?
              13       0.2000       ?
              14       0.2000       ?
              15       0.2000       ?
              16       0.2000       ?

Toggle Probe connection on/off, Make/Break Multiplexer connection,
Set cable length, Vp, DIST/DIV, etc., or <Esc>.
```

Repeat this process until all the multiplexers that are physically connected (or that will be physically connected) to multiplexer 1 are shown as connected in software as well. When finished, press the Esc key. Assuming that two multiplexers were connected to multiplexer 1 the next screen will be:

```
Connection Setup
Multiplexer number, type [in brackets], and address.
No.[TYPE] Address
1[1] 1
   2[1] 2
   3[1] 3

Enter number corresponding to location in tree (Press <Enter> to exit):
```

This screen also assumes that the addresses of the three multiplexers were 1, 2, and 3 for multiplexer 1 (MUX level 1) and multiplexers 2 and 3 (MUX level 2), respectively. The addresses could just as easily have been 16, 13, and 5.

Now the probe connections to multiplexers 2 and 3 should be set up. Press 2 to see the connection setup screen for multiplexer 2. Move the highlighted area with the cursor keys and press P until a plus sign appears for every channel to which a probe is physically connected. Move to the 'Probe Length' column and enter the actual probe length for each connected probe. Finally, move to the 'Acquire What?' column and make entries indicating the desired type of data acquisition for each probe. The following figure shows the setup for multiplexer 2 when 12 probes, each 20-cm long, have been set up on the first 12 channels. Water content has been chosen as output, not water content and BEC.

```
Channels connected to TDR probes are marked with pluses (+), channels
connected to other multiplexers are marked with number of multiplexer.
Working on multiplexer number 2, model: TR-200. Navigate with cursor keys.
  Type of   Channel    Probe     Acquire
Connection    No.    Length (m)   What?
    +          1       0.2000       W
    +          2       0.2000       W
    +          3       0.2000       W
    +          4       0.2000       W
    +          5       0.2000       W
    +          6       0.2000       W
    +          7       0.2000       W
    +          8       0.2000       W
    +          9       0.2000       W
    +         10       0.2000       W
    +         11       0.2000       W
    +         12       0.2000       W
              13       0.2000       ?
              14       0.2000       ?
              15       0.2000       ?
              16       0.2000       ?

Acquire Water content or Bulk EC or Both or Neither, or <Esc>.
```

Press Esc when through setting up the probe connections for multiplexer 2, and the Connection Setup screen will appear again. Now press 3 to set up multiplexer 3 probe connections, etc. The following figure shows the screen when 8 probes, each 20-cm long, have been set up for the first 8 channels of multiplexer 3. Note that, with the highlighted area focused on the probe connection to channel 8, the user may press S to set the cable length, VP, and DIST/DIV values for this probe if the cable tester, multiplexers, and probes are all installed and working. See Section 2.6 for details of these settings.

```
Channels connected to TDR probes are marked with pluses (+), channels
connected to other multiplexers are marked with number of multiplexer.
Working on multiplexer number 3, model: TR-200. Navigate with cursor keys.
  Type of   Channel    Probe     Acquire
Connection    No.    Length (m)   What?
    +          1       0.2000       W
    +          2       0.2000       W
    +          3       0.2000       W
    +          4       0.2000       W
    +          5       0.2000       W
    +          6       0.2000       W
    +          7       0.2000       W
    +          8       0.2000       W
               9       0.2000       ?
              10       0.2000       ?
              11       0.2000       ?
              12       0.2000       ?
              13       0.2000       ?
              14       0.2000       ?
              15       0.2000       ?
              16       0.2000       ?

Toggle Probe connection on/off, Make/Break Multiplexer connection,
Set cable length, Vp, DIST/DIV, etc., or <Esc>.
```

Repeat this process to set up probe connections for every multiplexer that has been connected to multiplexer 1.

When all multiplexer and probe connections have been set up in software, press Enter at the Connection Setup screen. A screen similar to the following will be displayed. In this example, the previous setup (not shown) had 5 probes assigned to multiplexer 1 and there were no other multiplexers. The current setup has 2 more multiplexers and no probes assigned to multiplexer 1 so there were no probes in common between the old and new setups.

```
There were 5 probes in the system before changes.
There are 20  probes in the new system.
Looking at old probe list...
There were 0 probes common to new and old lists.
Looking at new probe list...
Number of probes in old list: 5
There were 20 new probes.
These will be added to the end of the acquisition list.
Press any key to continue ...
```

Pressing any key will display the following screen which shows the default sequential order of acquisition of data from the probes in the system. You may follow the prompts and move individual probes to different places in the order of acquisition. Or, you may automatically sort the probes in one of two ways. One sort ranks the probes by multiplexer number and then by channel number on each multiplexer. The other sort is the result of a recursive search of the multiplexer and probe setup. The recursive search order is that used by TACQ prior to the July, 1997 release. If many new probes have been added to ones previously assigned to the system, you may want to press S or R to sort them rather than moving them individually. Press Esc when finished arranging the order of acquisition and the Software Setup menu will appear.

```
Sequential acquisition order:
   1> mux  2, chan.  1          Re-arrange acquisition order of probes:
   2> mux  2, chan.  2          [M]ove one probe at a time;
   3> mux  2, chan.  3          [S]ort by mux #, and channel # on mux;
   4> mux  2, chan.  4          Sort by [R]ecursive search (TACQ default);
   5> mux  2, chan.  5          <Esc> to exit:
   6> mux  2, chan.  6
   7> mux  2, chan.  7
   8> mux  2, chan.  8
   9> mux  2, chan.  9
  10> mux  2, chan. 10
  11> mux  2, chan. 11
  12> mux  2, chan. 12
  13> mux  3, chan.  1
  14> mux  3, chan.  2
  15> mux  3, chan.  3
  16> mux  3, chan.  4
  17> mux  3, chan.  5
  18> mux  3, chan.  6
  19> mux  3, chan.  7
  20> mux  3, chan.  8


Press [M] to move; then use <Pg-Up/Pg-Dn/↑↓>. Press <Enter> to end move.
```

If a Tektronix 1502B or 1502C cable tester is being used, pressing L at the Software Setup menu allows the user to set in software the distance (cable length) to each probe individually; and to set the Vp and DIST/DIV settings for each probe to the optimal settings for data acquisition given that probe's length. The next section describes how to do this. When finished, exit Software Setup by pressing Esc. Be sure to press Y to save the setup to disk.

2.6 Setting Cable Lengths, Vp, Dist/Div

With the Tektronix 1502B or 1502C cable testers, different cable lengths are accommodated by having the user interactively set the wave form horizontal position on the cable tester as the computer records the distance setting. Different rod lengths on different probes are accommodated as well (see Section 2.5). The Vp and DIST/DIV settings can be set interactively so that wave forms for probes having different rod lengths still occupy the full screen. This results in the best possible resolution for any rod length; and it ensures that there are an equivalent number of data points for graphical interpretation, no matter what the probe length. The program will recommend a good combination of Vp and DIST/DIV settings for the rod length of each probe. The recommended settings provide the best resolution (widest wave form) possible while ensuring that the wave form will not be too wide to fit the screen when the soil is saturated (the wave form becomes wider as the soil becomes wetter). The settings are stored automatically in file TACQ.INI and are used every time the program is run until changed by the user. When wave forms are interpreted for water content, the Vp, DIST/DIV and probe length settings are used in the calculations of the travel times. When wave form data are stored on disk these settings are stored as well (see Section 2.8 on data file formats) so that a program that subsequently reduces wave forms to water contents can read in the setting values and correctly interpret the wave forms. For instance, TACQ.EXE will read in the wave form files previously stored by TACQ.EXE (say, in the field) and correctly interpret the wave forms based on the individual Vp, DIST/DIV and probe length settings for each probe.

This section does not apply to systems using the older Tektronix 1502 analog cable tester which can only be adjusted manually. With the 1502, the user must make sure that travel times, from the cable tester to the probe handles, are equivalent (equivalent total cable length) for all probes in the system. Different probe lengths can be used, but for the 1502 the DIST/DIV and Vp settings must be those needed for the longest probes because these settings remain constant unless changed by the user on the front panel of the cable tester. The shorter probes will have correspondingly shorter wave forms on the screen, resulting in loss of resolution.

The interactive process begins in the Setup part of the program. Since this process uses the actual wave forms from the installed probes, the system setup must be complete before cable lengths and wave form positions can be set in this manner. This means that the multiplexers must be wired and powered, and connected to the computer via cable TR-2200. The probes must be installed and connected to the multiplexers. The multiplexers must be interconnected with coaxial cable (TR-1058), and the primary multiplexer must be connected to the cable tester with coaxial cable. See Section 1 for instructions on physical connections. All items in the Software Setup menu above “Probe Cable Length, Vp, DIST/DIV” must be completed so that communications between the computer and cable tester, and between the computer and multiplexers can be implemented. Note, however, that cable length, Vp, and DIST/DIV values for individual probes may be set for each probe during the Multiplexer and Probe Connection Setup (Section 2.5), if all items in the Software Setup menu above “Multiplexer and Probe Connections” are correct and the hardware is correctly installed as just described. If accessed from the Multiplexer and Probe Connection Setup, the cable length, Vp, and DIST/DIV setup proceeds in the same way as described below. Accessing this setup from the Multiplexer and Probe Connection Setup may save considerable time if the system has been set up previously and changes are needed for only one or a few probes.

Press L at the Software Setup menu to begin. The following screen will appear (The multiplexer and line numbers may be different for your system. Line means channel.):

```
Switched to line 1 of multiplexer 2
```

Note that the computer has switched the multiplexers so that the first probe on the second multiplexer is connected to the cable tester. In this example the primary multiplexer has a secondary multiplexer connected to its channel 1; and the secondary multiplexer has a probe connected to its channel 1. In general the program looks at the first channel of multiplexer 1 and if a multiplexer is connected to this channel that multiplexer will be multiplexer 2. The program will look at the first channel on multiplexer 2 and if another multiplexer (no. 3) is connected to this channel the program will look at channel 1 on multiplexer 3. In other words if a multiplexer is connected to a channel the program first looks at channels on the connected multiplexer, otherwise it looks at the probe and then goes to the next channel. (Note that we do not recommend hooking multiplexers together three deep in this manner. We recommend using one primary multiplexer with second level multiplexers connected directly to input channels of the primary multiplexer.)

After a brief time the program will display the wave form on the manipulation screen (Fig. 2-6). Because the cable tester initializes at start up to put the cursor at zero distance, when you are first setting up a system you will likely see a wave form like the one displayed in Fig. 2-6. This shows the first meter of cable. Usually you must search for the probe wave form by using the F and B keys to move forwards and backwards along the wave form; or, press 'E' to enter the distance to the wave form if you have an idea what that is. Pressing the F and B keys will move the window forward (longer distances) and backward, respectively, one window width at a time. Pressing H and then F or B, respectively, moves the window one half of its width in the respective direction. The user must adjust the view forwards or backwards until the wave form is properly positioned. An improperly positioned wave form cannot be correctly interpreted for water content determination by the software. Positioning is done by pressing the F, B, and H keys; by using the S key to fine tune the starting point (left hand side of the screen); and by changing the wave form width on the screen by changing the Vp and DIST/DIV settings. The first step is to find the part of the wave form that represents reflections from the TDR probe. To make a good guess at the distance to the probe we must first understand the concepts of Vp and DIST/DIV and how these settings affect the apparent distance and wave form width.

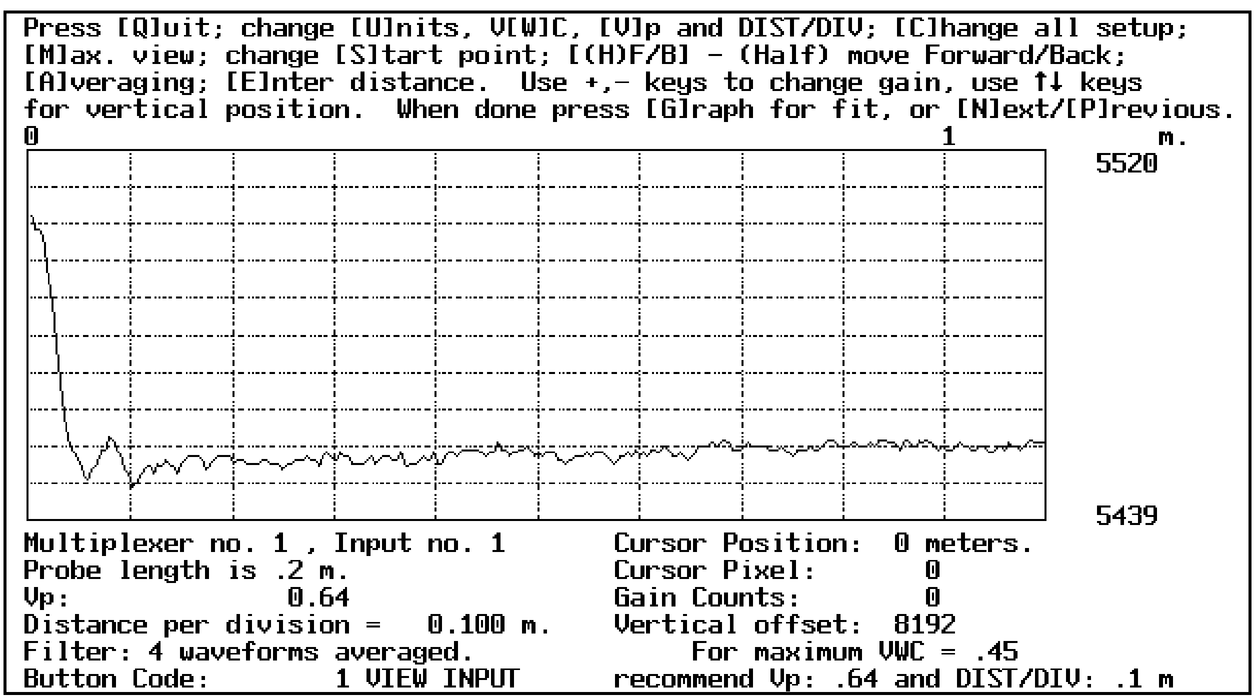

Figure 2-6. Wave form manipulation window before probe wave form is located.

The DIST/DIV (distance per division) setting dictates the width of each division of the window in length units. There are 10 divisions, so the window width is 10xDIST/DIV. The Vp is the relative velocity of propagation (relative to the speed of light, c) that the cable tester uses to convert time to distance before displaying the data. Changing either the Vp or DIST/DIV values will change the horizontal width of the wave form shown on the screen. Note that the cable tester actually measures time, not distance, but it displays distance. The distance displayed on the screen will be correct only if the Vp setting is appropriate for the cable being used. This is because different cables use different plastic insulating compounds between the inner conductor and outer conductor (shield), and the different permittivities of these compounds cause the TDR signal to travel faster (lower permittivity) or slower (higher permittivity). For most cables with polyethylene insulation, a Vp setting of 0.66 will cause the distances calculated by the cable tester to be close to the actual distances along the cable. Changing Vp will affect the distances shown on the graph; and it will change what is shown in the graph window. Using a smaller Vp will cause the apparent distance calculated by the cable tester to be smaller (distance = velocity x time) and features on the screen will become smaller in width. In effect, the window shows a longer actual view of reflections from the wave guide (this may include views of the wave guide inside the cable tester, in the cable between cable tester and probe, and/or the probe and beyond the probe).

The following procedure will place the wave form fairly close to the desired position. Press V and enter 0.66 followed by the Enter key. Then use the up and down cursor keys to select a DIST/DIV setting equal to the one recommended in the lower right corner of the screen. Measure the length of cable between the cable tester and the probe. Make sure that the units of your measured distance match those on the screen. Press E and enter the distance measured minus about 0.3 m or 1 ft (for Alpha RG58. For Belden RG58 use 0.1 m). The wave form should now include some of the reflections from the probe. Figure 2-7 shows a wave form for a 20 cm probe with a 3 m cable that was positioned using this procedure. Although this is not the desired position, it is close enough to allow fine tuning.

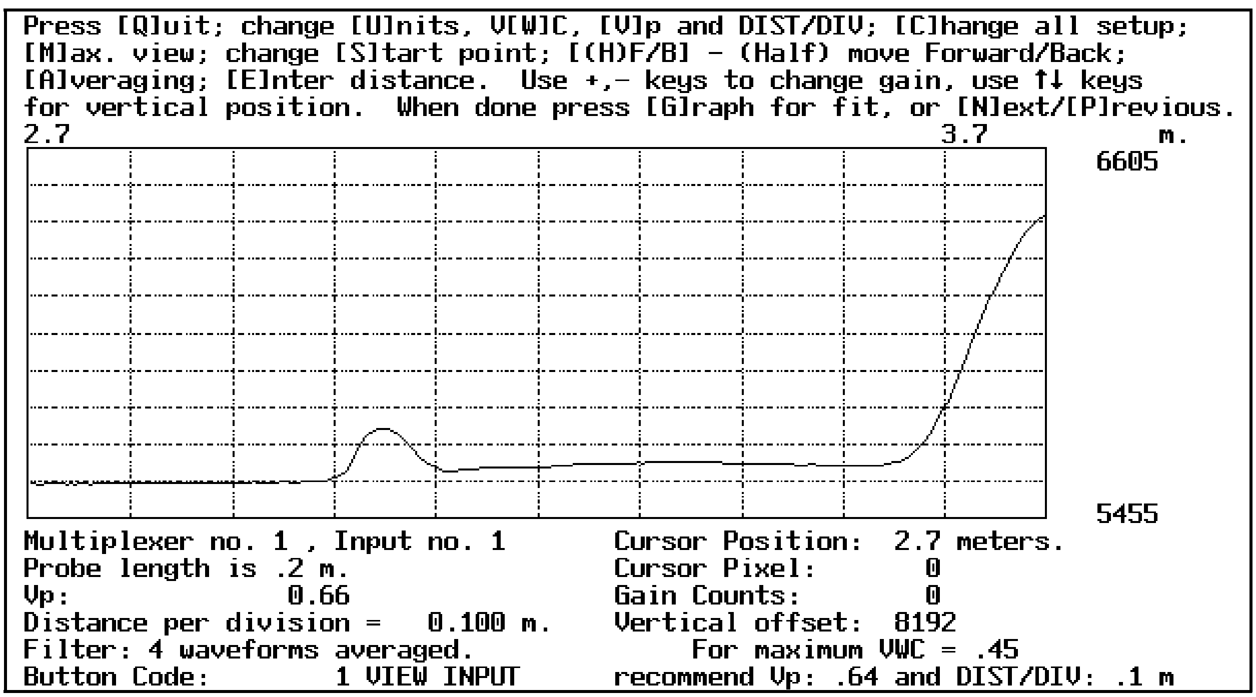

Figure 2-7. Wave form manipulation screen for probe on 3 m cable after first attempt to position wave form. Probe is in saturated sand.

In the lower right corner of the screen are given recommended Vp and DIST/DIV settings for the current probe length and maximum expected water content. If your maximum expected water content (usually the saturated water content or total porosity in m^3 m^{-3}) is not the same as that shown, press W to change it. Press V to change Vp and DIST/DIV to the recommended values, thus adjusting the wave form to the proper width. See Section 7.6.1 and Appendix 7-A for a definition of proper wave form width and explanation of how the program determines the best Vp and DIST/DIV settings.

Fine tune the position of the first peak by pressing S and moving the vertical line with the cursor keys. When finished, pressing Esc will re-set the left hand border of the screen to the new position of the line. The desired position of the first peak is just to the right of the first vertical grid mark (Fig. 2-8). A typical wave form for a probe in dry sand is shown in Fig. 2-9. If the wave form is too far to the left, it may quickly be moved to the right by pressing E and entering a distance slightly less than that shown just above the upper left corner of the graph.

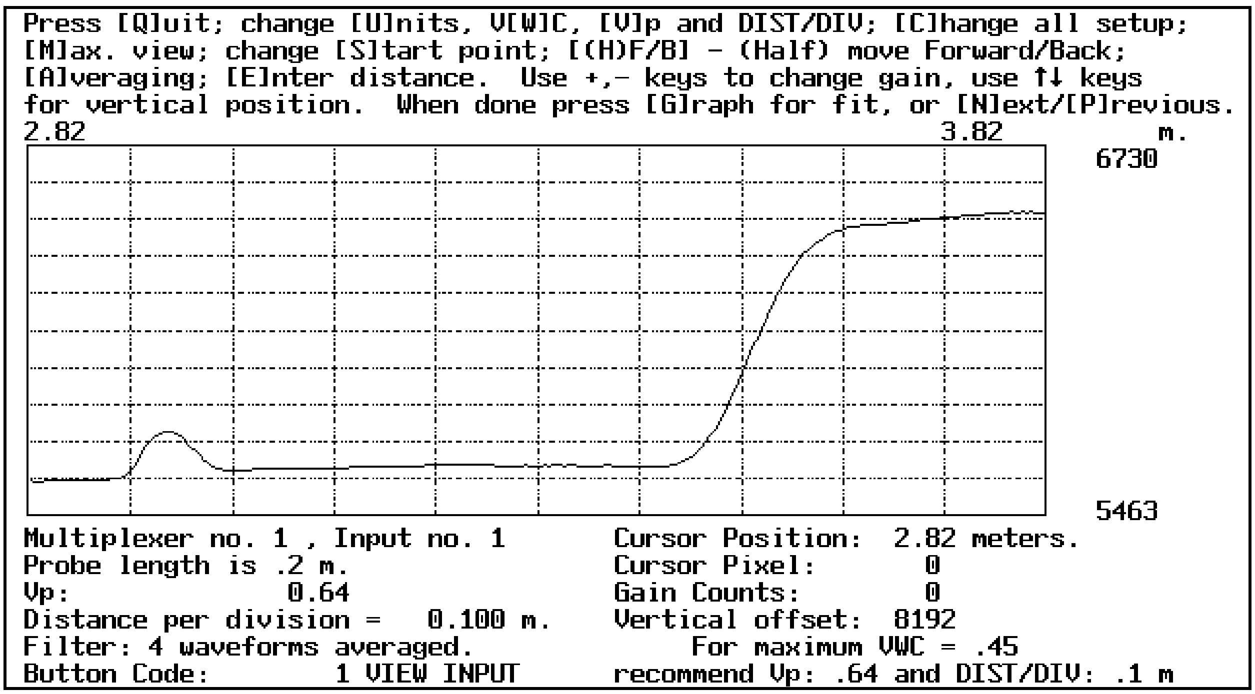

Figure 2-8. Wave form manipulation screen for probe on 3 m cable after adjusting the left hand border by pressing the S key and using the cursor keys. Probe is in saturated sand.

There is usually no need to adjust the vertical position and gain; but, when the wave form is properly positioned horizontally, the vertical position can be adjusted using the up and down arrow keys; and the gain can be adjusted using the + and - keys (Fig. 2-8). Care should be taken that the wave form is not over-magnified using the gain control nor positioned too high or too low. Since the wave form shape may change over time, as the soil wets and dries, allowance must be made for these shape changes so that the entire wave form will remain on the screen at all times. A good rule is to not adjust the gain and vertical position controls.

Pressing A allows the filtering level to be set (number of wave forms averaged before mean wave form is sent to the computer by the 1502B/C). In many situations no averaging will produce acceptable wave forms. If noise is causing problems with graphical interpretation of wave forms the filtering level may be adjusted for up to 128 wave forms averaged. Note that the wave form interpretation part of TACQ allows wave form smoothing which may be adequate to overcome any noise problems.

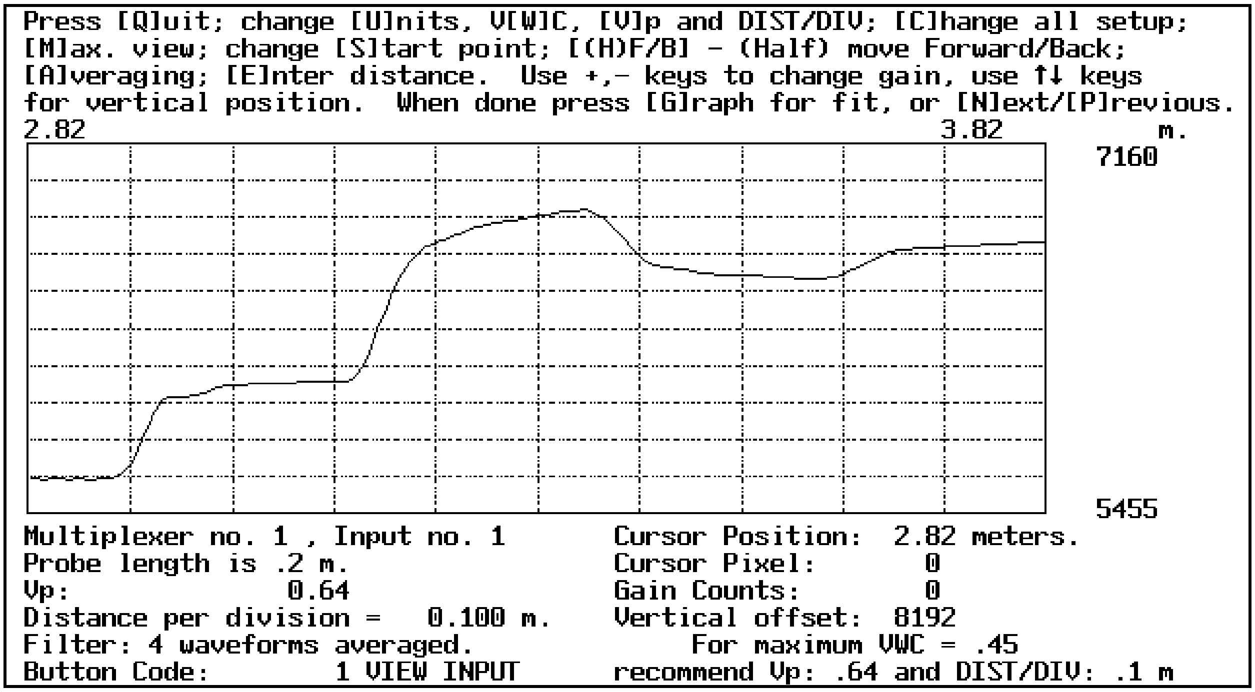

Figure 2-9. Wave form manipulation screen for probe on 3 m cable after adjusting the left hand border by pressing the S key and using the cursor keys. Probe is in air dry sand.

When finished adjusting the wave form, press N to see the wave form for the next probe on multiplexer 2; or, press G to see the graph of the present wave form with the tangent lines fitted for water content determination. Right now it is preferrable to press N rather than G. After all the wave form positions are set up you can go back and look at the fitting. When the user presses N, the system switches to the next probe on multiplexer 2. (The user may also press P to return to the previous wave form.) Find and position the wave form for this probe and repeat the process until all probes on all multiplexers (as chosen by the user in Connection Setup) are set up. If this is the first time a system has been set up, the program will use the settings from the previous probe to set the inital position and width of the next probe. The user may accept this by pressing N to go to the next probe, or make adjustments if necessary. At the end of this process a prompt will appear asking if the information should be saved. Press Y to save this setup for distance to probe, Vp, and DIST/DIV. You will be returned to the Software Setup screen. Press Esc to exit Software Setup and press Y when prompted to save the entire setup.

If 'G' is pressed (Fig. 2-8) the computer acquires the wave form and displays it (Fig. 2-10). By pressing 'D' (re-do) when the graph is displayed, the user has the option of changing various settings that affect how the travel times are found. See section 2.7, Algorithms for Reducing Wave Forms to Water Contents, for more information. Note that the wave form is displayed on the lower part of the computer screen while its first derivative is displayed above it. The intersecting straight lines represent tangents fit to the data for interpreting travel times. The vertical straight lines indicate key travel times (from left to right: t1.bis, t1, and t2). The user may return to the Wave Form Manipulation screen to adjust the wave form position. This is done by pressing D for re-do and then W for manipulate [W]ave form.

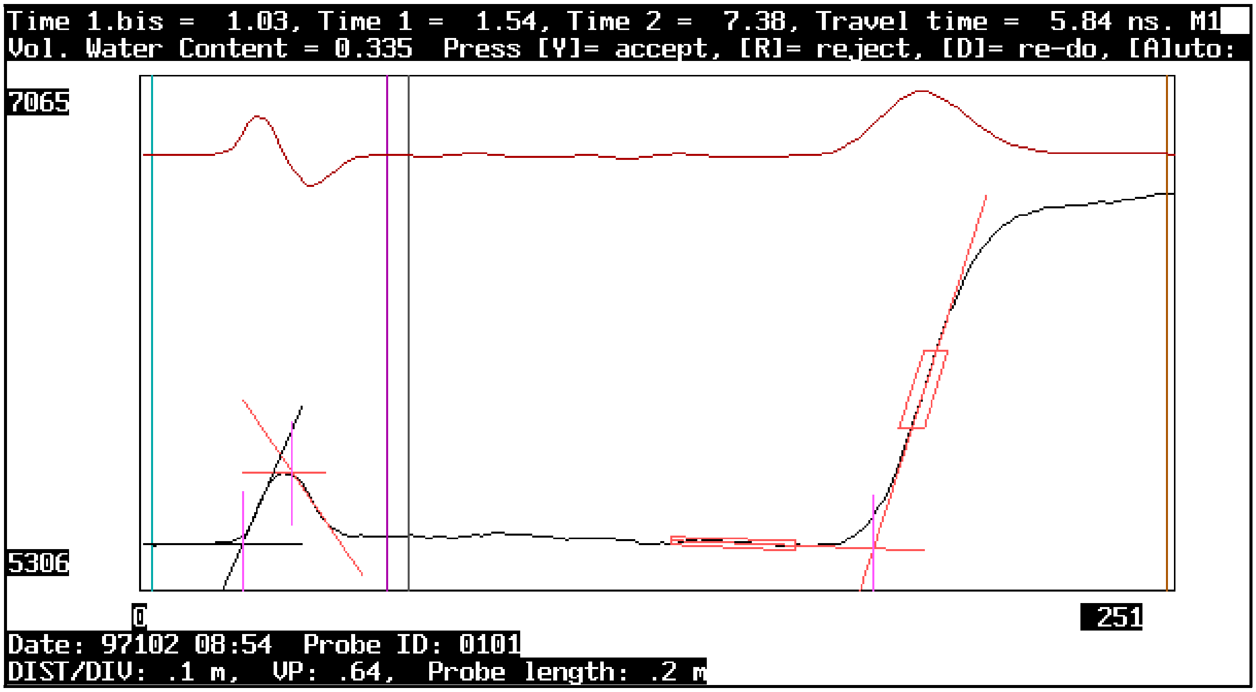

Figure 2-10. Example graphical interpretation screen for probe in wet sand.

2.7 Algorithms for Reducing Wave Forms to Water Contents

As noted in the previous section the algorithms used for wave form reduction may be changed by the user. This can be accomplished from the Software Setup menu by pressing I; or while setting cable lengths, etc. interactively as noted above. The user can also press F at the main menu and then press S for single wave form acquisition. This will cause the program to acquire a wave form and display it in the wave form manipulation screen. Pressing G at the wave form manipulation screen will cause the graphical interpretation screen to appear (see example in Fig. 2-10). When a screen like Figure 2-10 is displayed, pressing D will cause the prompts in Figure 2-11 to appear. The user may change the algorithm settings and save those changes. Another way to access algorithm settings is to press F at the main menu, followed by R to read in a wave form file for reduction to water content. The settings can be accessed as each wave form is analyzed. For the present discussion we will assume that the user has pressed I at the Software Setup menu. This section also assumes basic understanding of wave form morphology and terminology as discussed in Section 7. Wave form features discussed here are shown in Figure 2-12 (or 7-3). Changes can be made affecting the determination of travel times (t1 and t2), smoothing, flagging of negative water contents, screen appearance, etc. (Fig. 2-11).

```
Change method: Time [1], Time [2], [V]erbose mode, [S]moothing, [C]orrection,
[N]egative Theta limit, [M]onochrome, [L]ength, go to [D]ate, [T]ry fit,
Manipulate [W]ave form, [Q]uit, or save to [F]ile:
```

Figure 2-11

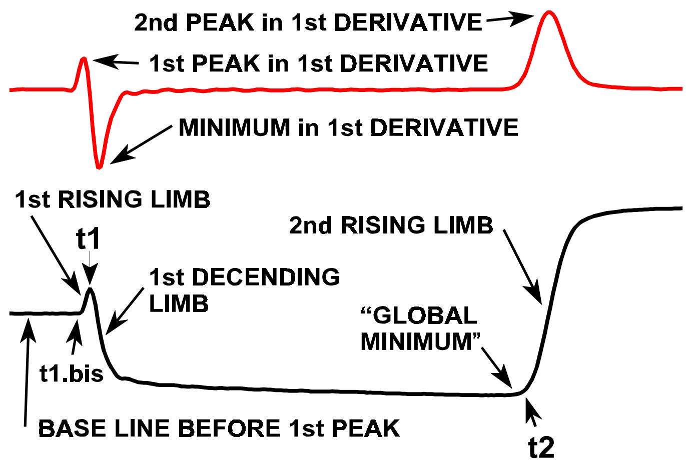

Figure 2-12. The TDR wave form (bottom) and its first derivative with respect to time(top), with features labeled.

The 'verbose mode' settings are several. The first, if enabled, will print to the screen various intermediate results during the wave form reduction to water content. These are primarily of interest to the programmer. The second verbose mode setting can enable a warning that time 2 is much greater than the time of the minimum value of the wave form after time 1. The third setting can enable a plot of the smoothed wave form. The fourth setting can enable the exit from automatic mode if an error is encountered by the program. This is the most important setting for the user. If unattended automatic data acquisition and reduction of wave forms to water contents is desired then the fourth setting should be to disable the exit from automatic mode. This is so that a bad wave form resulting from disturbance of a probe or electromagnetic noise cannot stop the unattended data acquisition.

The 'negative theta limit' is present because wave forms from very dry soils can sometimes result in water contents that are close to zero. Random variations will result in negative water contents being calculated. Adjusting the negative theta limit allows some negative values to be accepted without the program being stopped. Values below the limit will cause the program to stop and alert the user. For unattended data acquisition we recommend setting the negative theta limit to -100.

'Smoothing' is done by a Savitsky-Golay routine. Using a 9 point smooth of the wave form and a 5 point smooth of the first derivative works well. Too much smoothing will cause tangents to be placed incorrectly. Too little smoothing will cause noise in the first derivative leading to noise in the water content determinations (primarily due to noise in the determination of time 2). Press S to change smoothing settings.

The 'Correction' selection allows a linear correction factor to be entered. This changes the travel time directly. An example of its use would be when the probe length was incorrect for some reason. A linear correction on travel time would compensate for this. Another example would be if Vp or DIST/DIV were set differently on the older model 1502 cable tester and in software during a prior data acquisition. Linear corrections can be calculated and entered here to correct the discrepancy.

'Change to Monochrome' allows the colored tangent lines to be rendered in black and white. This enhances visibility on some monochrome monitors or LCD panels.

'Length' of the probe may be changed (temporarily) by pressing L. To change the length permanently use Multiplexer & Probe Connections in Software Setup.

'Go to Date' allows the user to skip the data in a wave form file until a specific day and hour.

'Try fit' applies the currently selected algorithms to the wave form analysis of the present wave form and presents a revised graphical interpretation screen. The user may make more changes to the algorithms after this, or press R or Y to reject or accept the analysis and move on to the next wave form. The currently selected algorithms will be applied to the subsequent wave forms.

‘Manipulate Wave form’ allows the user to return to the Wave Form Manipulation Screen and adjust the wave form position. This prompt is only seen if the wave form was acquired directly from the cable tester. When wave forms are read in from a previously acquired file the prompt is not seen.

‘Save to File’ saves all the currently selected algorithms to file TACQ-TDR.INI so that they will become the default wave form analysis methods the next time that TACQ is run.

Pressing 1 or 2 allows the user to make changes to the algorithms used to find t1 and t2, respectively. These will be described in more detail below.

Press 1 to make changes in methods for finding t1 and the menu shown in Fig. 2-13 appears.

```
Change [S]wath width to right of peak, [B]eginning point for data analysis,
Safety [L]imit, swath for max. 1st [D]erivative, [M]ethod, or use [C]ursor:
```

Figure 2-13

The '[S]wath width to right of peak' refers to how many data points of the wave form to the right of the first peak in the wave form will be searched to find the most negative first derivative. The point at which the most negative first derivative occurs is the point of steepest descent of the wave form after the first peak. A tangent line is fit to the wave form at this point. The intersection of the tangent line and a horizontal line drawn across the first peak in the wave form is one way to define time 1 (t1). In extremely dry or loose soils the wave form sometimes displays double first peaks. The limited swath of data examined for the most negative first derivative eliminates the possibility that the tangent to the descending wave form would be drawn after the second peak.

The '[B]eginning point for data analysis' allows some data at the start of the wave form to be disregarded. This has little usefulness for data acquired from the Tektronix 1502B or 1502C digital cable testers. However, data from the Tektronix 1502 must be digitized externally and timing problems can sometimes cause noise in the data at the start of the wave form.

The 'Safety Limit' allows the exclusion of data at the start of the wave form when searching for the first peak in the first derivative.

The 'swath for max. 1st [D]erivative' puts an upper limit on the data that will be searched for the first peak in the first derivative. This prevents the second peak in the first derivative from being confused with the first peak.

The '[M]ethod' selection allows two choices for methods of computing time 1. Method 1 uses the intersection between a horizontal line, drawn across the top of the first peak in the wave form, and a tangent line fit to the descending wave form immediately after this first peak. This used to be the more commonly used method. Method 2 finds a time associated with the intersection of a horizontal line, drawn through the base line of the wave form before the first peak, and a tangent line fit to the ascending wave form before the first peak. This time (t1.bis) is less than time 1 but the interval between this time and time 1 is reproducible. This is essentially the pulse transit time in the handle. The interval can be measured for any probe by putting the probe in saturated sand and making repeated measurements. TACQ can then be used to analysis the wave forms to find repeated values of the two time 1 values (t1.bis and t1). Subtracting t1.bis from t1 and plotting the results in a spreadsheet will show graphically what the transit time is. Enter the transit time when prompted here. Method 2 is much more reliable when soils are dry. See Section 7 for more information. An example graphical interpretation screen for a dry sand using method 2 is shown in Fig. 2-14.

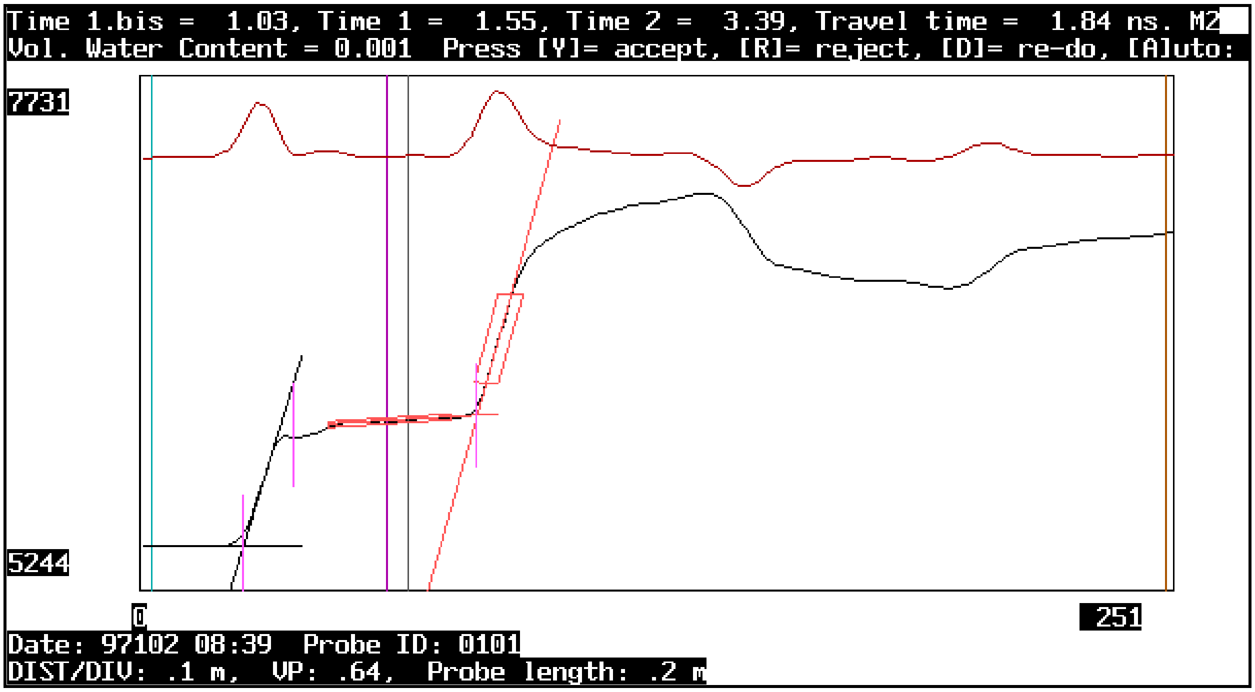

Figure 2-14. Example graphical interpretation screen for probe in dry sand.

The ‘use Cursor’ selection allows the user to choose the placement of t1 using a cursor moved with the left and right cursor keys.

Press 2 at the menu shown in Fig. 2-11 to change methods for finding time 2 (t2) and Fig. 2-15 appears.

```
[B]ase line fit, [R]ising limb fit, [I]nflection point, change [E]nding point
for data analysis or use [C]ursor:
```

Figure 2-15

The '[B]ase line fit' refers to the method used to fit a base line to the bottom of the wave form after time 1. Two methods are available. The most commonly used is to draw a horizontal line tangent to the lowest point in the wave form after time t1. The other method is to fit a line by regression to a swath of points. The second method is recommended in most cases. After pressing B and selecting the base line fit method a '[S]wath width' choice will be shown. This defines the number of data points (usually 30) included in the fit. Below we’ll discuss how the beginning point of the swath of points is chosen.

The '[R]ising limb fit' can be either a straight line fit or a polynomial fit. In the case of a polynomial fit the first derivative of the polynomial, at the midpoint of the rising limb, defines a line tangent to the rising limb analogous to the line defined by a straight line fit to the rising limb. In either case the number of points included in the fit can be set by the user so that the curved ends of the rising limb can be effectively excluded from the fit. In all cases t2 is defined by the intersection of the line tangent to the rising limb and the base line.

The 'Ending point' setting allows the exclusion of data at the end of the wave form. This is sometimes necessary for data from the analog Tektronix 1502 as noted above.

The 'use Cursor' selection allows the user to choose the placement of t2 using a cursor moved with the left and right cursor keys.

The '[I]nflection point' refers to the method of finding the center of the rising limb of the wave form after time 2. Defining the center of the rising limb is necessary so a line tangent to it can be found. If the wave form is well defined, with a steeply rising second inflection (rising limb), then the first derivative will have a well defined peak centered at the midpoint of the rising limb and this point can be used to define the middle of the set of points used to fit the line tangent to the rising limb. However, if the soil is saline and wet, or very wet with a high clay content (especially high CEC clay) the wave form may have a very shallow second inflection. In this case the first derivative will not have a reliably well defined peak. The peak may be lost in noise. But, also in this case, the low point in the wave form after the first peak will always occur at the right hand side just before the second inflection. Therefore, when the second peak in the first derivative is below a certain value the low point in the wave form (local minimum) can be reliably used to index the second inflection. In this case the middle of the rising limb is taken to be a user-set number of points (30 is a good choice) to the right of the local minimum. The choices for finding the second inflection are therefore: 'Highest derivative', 'Local minimum', and 'Automatic'. The 'automatic' setting is preferred. If 'automatic' is chosen the user must specify a value of the peak in the first derivative; below which the program will use the local minimum method and above which the program will use the highest derivative method. A good choice is 6. A starting point for the search for the second peak in the first derivative is also specified to eliminate the possibility that the first peak in the first derivative or a secondary first peak (as described above) would be found. If either the automatic or local minimum method is chosen, the user specifies a number of points to the right of the local minimum to be used as the center of the rising limb.

For the algorithms described above the default settings work well with most systems. But it can be time consuming to repeatedly run TACQ.EXE to acquire wave forms and change settings. A more effective method is to set up TACQ.EXE to automatically acquire wave forms from all the probes in the system. Then, in more comfortable surroundings, the wave form file can be read back into program TACQ.EXE and the effect of algorithm changes explored without the wait for cable tester response that is inherent while acquiring data. For a more thorough discussion of the algorithms used for wave form interpretation see Section 7.

2.8 File Formats

There are four file formats used by TACQ. Three of these are shared by files that are written to during automatic data collection, and files that are created manually. The fourth is only created during manual operation of TACQ. File naming conventions differ between automatically collected files and manually collected files.

2.8.1 Automatically Collected Files

Data files created automatically by TACQ are of three kinds; files containing wave forms and associated data needed for proper interpretation of the wave forms (e.g. Vp, distance per division, distance units, probe length); files containing water contents, travel times and apparent permittivities; and files containing relative wave form voltages useful for calculation of bulk electrical conductivity. Each file type is designated by a one letter code in its file name: T for wave forms, W for water contents, and E for bulk electrical conductivity. The water content files also contain the travel times and apparent permittivities; either of which could be used in a spreadsheet to compute water contents using a calibration equation of the user's own choosing. New files are created each day. This prevents data loss of more than a day's data if there is a power failure or system crash for some reason during file I/O. File names have the format yyyydddX.SUF where yyyy is the current year, ddd is the day of year, X is the code identifying the file type, and SUF is a file name suffix of up to 3 characters specified by the user in the Setup part of the program. Thus for a water content file containing data for day 206 of year 1994, the file name would be "1994206W.TAC" if the user had chosen "TAC" for the file name suffix. A file containing wave forms for the same day and file suffix would be named "1994206T.TAC". The user supplied file name suffix serves as an identifier to distinguish files from one TDR system from those written by another system.

Wave form files contain data for one wave form on each line. From left to right on the line the numbers are: an integer formed from the year and the day of year (e.g. 1994206 for our example); the hour, minute and seconds separated by colons (e.g. 19:01:51 for one minute, 51 seconds after 7 pm); an integer formed from the multiplexer number and probe number on that multiplexer (e.g. for multiplexer number 7 and probe 4 the number would be 0704, for probe number 16 the number would be 0716, for multiplexer number 12 and probe number 3 the number would be 1203); the propagation velocity factor; the distance per division; the units code for the distance per division (1 for feet, 2 for meters); the probe length in meters; the number of data points in the wave form; and finally, the sequential data representing the wave form from left to right on the cable tester screen. An example for 7:01:51 pm on day 206 of 1994 is:

1994206, 19:01:51, 1101 0.99 1 1 .2 251 ....

For this example the multiplexer number was 11, the probe was connected to input number 1 on that multiplexer, the propagation velocity factor was 0.99, the distance per division value was 1 and the units were feet, the probe length was 0.2 m and there were 251 data points in the wave form (data not shown). The wave form data are Y-values (related to voltage) only. The X-values are not needed since the number of points in the wave form and the Vp and distance per division settings can be used to calculate the time interval between data points along the X-axis. For the Tektronix 1502B/C cable testers one wave form and associated data will take about 1546 bytes of hard disk space (251 data points in the wave form). Thus, a 120 Mbyte hard disk can store about 77,000 wave forms.

Water content files are formatted for easy input to a spread sheet so some numbers are in double quote marks. Each line contains data for one measurement. For the same probe used in the previous example the first line of data might look like:

1994206 19:01:47 "1101" 1.690451 2.197025 6.161919 3.964894 0.1649 8.8306

where the year and day of the year are given as one number, the time is given to seconds in 24 hour format, and the multiplexer number and probe number are in the double quoted string; followed by the time from the left hand side of the screen to t1.bis, the time to t1, the time to t2, the travel time, the water content and finally the apparent permittivity. The travel times are two-way - see Section 7.2, The TDR Method for Water Content Determination, for an explanation of the two-way travel time and how it is used to calculate apparent permittivity. Each line takes about 79 bytes so a 120 Mbyte hard disk can store over 1.5 million readings. A 1 Mbyte PCMCIA SRAM card with DOS and TACQ.EXE installed has about 530 kbytes free RAM and can hold over 6700 readings. Larger SRAM cards are also available. Our subnotebook computer can boot from these PCMCIA cards. Thus, the hard disk can be removed to make the computer data logging system completely solid state with very low power consumption (about 290 mA at 12 VDC).

BEC data files contain 9 values on each line. For example:

1994206, 20:32:12, 0101 5459.562 5655.086 5457.88 6865.02 3910.72 5440.692

The first value is a combination of the year (first 4 digits) and the sequential day of the year; the second value is the hour, minute, and second; and the third value is the multiplexer number and channel on that multiplexer. For this example the data were taken on the 206th day of 1994 at 8:32:12 pm (20:32:12 in 24 hour format) from channel 1 of multiplexer 1. The six data values are the cable tester's digital representations of the wave form voltage at various points along the wave guide. These are called Vo, Vmin, Vo, Vf, Vi, and Vr, which are defined as follows:

V_O The voltage of the wave form before the first peak, i.e. the pre-incident pulse height. This is taken from the regular wave form that the user sets up for determination of water content. If the first peak is set to occur just at or after the first vertical division on the screen, then this value of V_O will be the average of about 15 to 25 points. The actual number of points depends on what the program determines to be the flat part of the wave form before the first peak. This value is determined by the program for the use of some who might want to use a particular method cited in a paper. This value is somewhat noisier than the second value of V_O (see below). The second value of V_O is preferred for BEC calculations.

V_{MIN} Again, this value is taken from the regular wave form that the user set up for determination of water content. It is the voltage of the minimum of the wave form between the first peak caused by the probe handle and the final reflection caused by the ends of the rods. Some persons have used this value for BEC calculations, but there are better methods now. It is output by TACQ for compatibility with older techniques. The value of V_{MIN} is more noisy than the others because it is a single point value, not an average. Applying more wave form smoothing will reduce the noise somewhat; but the extra smoothing may cause problems with wave form interpretation for water content. This is the only value that is taken from the smoothed wave form.

V_O The second value of V_O is acquired by first moving the 'regular' wave form view one tenth of its length to the left (one DIST/DIV to the left), and then taking the average of the first 25 data points. These data are the first 25 data to the left of the beginning of the regular wave form that the user set up for determination of water content. Normally the two values of V_O should be the same, but the first value is slightly more noisy because of the possibility that some data from the initial part of the rise of the first peak may inadvertently be included in the averaging.

V_F The voltage of the wave form at great distance (final voltage). To find this, the program sets DIST/DIV to 1 m or 2 feet, sets the wave form to start at 599 m or 1980 feet, and then takes the mean of the last 50 data points.

V_I The initial voltage of the wave form before the voltage pulse is injected. This is virtual zero for the TDR system and all other voltages may be normalized by subtracting V_I from them. The program sets DIST/DIV to 0.1 m or 0.5 foot, sets the start of the wave form to -0.51 m or -2 feet, and takes the mean of the first 25 data points. The negative distance setting means that the wave form that we are looking at here is inside the cable tester, before the BNC connector on the front panel and before the pulse is injected.

V_R This is called the relative voltage and is used in the paper by Baker et al. (1996. Agron. J. 88:675-682). It is determined from the same wave form as for V_I but is the mean of the last 25 data points of the wave form. This is in the cable outside the cable tester and after the pulse is injected. Note that the values of V_R, the first V_O, and the second V_O are all about the same, differing only due to changes in impedance due to cable resistance, cable type before and after the multiplexer (if there is one), noise, etc. In general Vr tends to be slightly smaller than either V_O value.

For information on how to calculate BEC from these data see (among others):

Dalton, F.N. 1987. Measurement of soil water content and electrical conductivity using time-domain reflectometry. In Proceedings of the International Conference on Measurement of Soil and Plant Water Status. July 6-10, 1987, Utah State University, Logan. Vol. 1, pp. 95-98.

Dalton, F.N. 1992. Development of time domain reflectometry for measuring soil-water content and bulk soil electrical conductivity. In G.C. Topp, W.D. Reynolds, and R.E. Green (eds) Advances in Measurement of Soil Physical Properties: Bringing Theory into Practice. Soil Sci. Soc. Am., Madison, WI.

Dalton, F.N., W.N. Herkelrath, D.S. Rawlins, and J.D. Rhoades. 1984. Time-domain reflectometry: simultaneous measurement of soil water content and electrical conductivity with a single probe. Science 224: 989-990.

Dalton, F.N., and M. Th. van Genuchten. 1986. The time-domain reflectometry method for measuring soil water content and salinity. Geoderma 38:237-250.

Dasberg, S., and F.N. Dalton. 1985. Time domain reflectometry field measurements of soil water content and electrical conductivity. Soil Sci. Soc. Am. J. 49:293-297.

Nadler, A., S. Dasberg, and I. Lapid. 1991. Time domain reflectometry measurements of water content and electrical conductivity of layered soil columns. Soil Sci. Soc. Am. J. 55:938-943.

Spaans, E.J.A., and J.M. Baker. 1993. Simple baluns in parallel probes for time domain reflectometry. Soil Sci. Soc. Am. J. 57:668-673.

Topp, G.C., M. Yanuka, W.D. Zebchuk, and S. Zegelin. 1988. Determination of electrical conductivity using time domain reflectometry: Soil and water experiments in coaxial lines. Water Resour. Res. 24:945-952.

Wraith, J.M., S.D. Comfort, B.L. Woodbury, and W.P. Inskeep. 1993. A simplified waveform analysis approach for monitoring solute transport using time-domain reflectometry. Soil Sci. Soc. Am. J. 57:637-642.

Zegelin, S.J., I. White, and D.R. Jenkins. 1989. Improved field probes for soil water content and electrical conductivity measurement using time domain reflectometry. Water Resour. Res. 25(11):2367-2376.

The paper by Wraith et al. is notable for simplicity, clarity, and a method for calibration.

The load impedance, Z_L, (ohms) is used in most methods of calculating bulk electrical conductivity:

$$Z_L = Z_{REF}(1 + \rho)/(1 - \rho)$$

where Z_{REF} is the output impedance of the cable tester (50 ohms), and where

$$\rho = E\text{-}/E\text{+}$$

where

$$E\text{-} = V_F - V_O$$

and

$$E\text{+} = V_O - V_I$$

For most methods only V_O (the second one), V_I, and V_F are needed.

4.8.2 Manually Collected Files

Three of the files created manually (e.g. by pressing F, A, S; or B; at the Main Menu) are identical in format to those created automatically; only the names differ. Wave forms are saved to a file with the WAV suffix and a user supplied prefix of up to 8 characters. For example if the user entered TEST_ONE as the prefix, the file name would be TEST_ONE.WAV. Water content files have the suffix WAT. For the TEST_ONE prefix a water content file name would be TEST_ONE.WAT. Data for bulk electrical conductivity would be in file TEST_ONE.BEC where the BEC is assigned by TACQ.

There is a fourth file type created by TACQ during manual data collection. The file name suffix is DIG and the prefix is the same as for the first 3 file types. This file contains the same wave form as in the *.WAV file. But, it is in the format used by the Tektronix program SP.EXE. It is created for compatiblity with programs that use that file format. The format contains some data not saved in TACQ's other file formats, including gain and vertical offset data, and a user-supplied comment.. TACQ can read this file type.